AD A052467

USAAEFA PROJECT NO. 75-19-2

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FLIGHT EVALUATION
HONEYWELL ULTRASONIC WIND VECTOR SENSOR SYSTEM
FIRE CONTROL WIND SENSOR REPORT

AD No.
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JUNE 1976

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UNITED STATES ARMY AVIATION ENGINEERING FLIGHT ACTIVITY
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REPORT DOCUMENTATION PAGE	READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER 14 USAAEFA [redacted] -75-19-2	2. GOVT ACCESSION NO. | 3. RECIPIENT'S CATALOG NUMBER 9
4. TITLE (and Subtitle) 6 FLIGHT EVALUATION, HONEYWELL ULTRASONIC WIND VECTOR SENSOR SYSTEM. FIRE CONTROL WIND SENSOR REPORT.	5. TYPE OF REPORT & PERIOD COVERED FINAL REP[redacted]T. Dec[redacted]75 - Jan[redacted]76
	6. PERFORMING ORG. REPORT NUMBER USAAEFA Project No. 75-19-2
7. AUTHOR(s) 10 BARCLAY H. BOIRUN, [redacted] GARY E. HILL, [redacted] JOSEPH C. MIESS	8. CONTRACT OR GRANT NUMBER(s) 12 51p.
9. PERFORMING ORGANIZATION NAME AND ADDRESS US ARMY AVIATION ENGINEERING FLIGHT ACTIVITY EDWARDS AIR FORCE BASE, CALIFORNIA 93523	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS EJ-6-NJ469-04-F6-U4
11. CONTROLLING OFFICE NAME AND ADDRESS US ARMY AVIATION ENGINEERING FLIGHT ACTIVITY EDWARDS AIR FORCE BASE, CALIFORNIA 93523	12. REPORT DATE 11 JUN[redacted]76
	13. NUMBER OF PAGES 54
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report) UNCLASSIFIED
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE NA

16. DISTRIBUTION STATEMENT (of this Report)

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17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Honeywell ultrasonic wind vector sensor
True airspeed
relative wind direction
3-dimensional velocity sensor

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Tests were conducted to evaluate the Honeywell ultrasonic wind vector sensor (UWVS) system as an airspeed and relative wind sensor system on the AH-1G helicopter. The prototype system included the sensor unit, electronic computer, and a set of velocity meters. The system measures the total flow velocity and 3-orthogonal velocity components which may be used to calculate aircraft true airspeed components, sideslip, and angle of attack. The tests were conducted on

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20. Abstract

an AH-1G helicopter, at Edwards Air Force Base, California, from December 1975 through January 1976. The UWVS system computed true airspeed and relative wind direction in a repeatable and accurate manner when operating in forward flight and free of the rotor downwash effects in all locations tested. The best performance was obtained with the system mounted above the rotor mast. When mounted below the rotor, significant nonlinearity and system error occurred, due to rotor wake flow and self-induced turbulence over the sensor, producing unusable results in some flight conditions. Inadequate airflow through the temperature probe was also noted in some low-speed conditions. If these problems are corrected, the UWVS system can be an effective three-dimensional velocity sensor, which could be calibrated to provide accurate helicopter airspeeds in most normal flight conditions.

PREFACE

The authors of this report wish to acknowledge the efforts of Mr. Frank J. Ferrin and Mr. John Peterson of Honeywell, Inc. for providing the system description in appendix B and the ground pace vehicle and wind tunnel data and analysis presented in appendixes C and E of this report. Although the data presented in appendix E was not part of the original test, it is included for general information.

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INTRODUCTION

BACKGROUND

1. The United States Army Aviation Engineering Flight Activity (USAAEFA) has previously tested several low-airspeed measuring systems on helicopters for the United States Army Aviation Systems Command (AVSCOM) under USAAEFA Project No. 71-30 (refs 1 through 6, app A). The Frankford Arsenal, Philadelphia, Pennsylvania, recently installed an air data system on the AH-1G as part of the enhanced Cobra fire control system. Performance data on the air data system were required to evaluate the system and optimize its operation on the fire control system. To meet this need, AVSCOM directed USAAEFA (ref 7) to conduct tests with the Elliott low airspeed system (LASSIE) installed on the AH-1G helicopter. A test plan (ref 8) was prepared by USAAEFA and approved by AVSCOM and Frankford Arsenal. Another system, the Honeywell ultrasonic wind vector sensor (UWVS) was later added to the test request and test plan. This report presents the results of the testing performed on the Honeywell UWVS system.

TEST OBJECTIVES

2. The general test objective was to determine the performance of the Honeywell UWVS system in all flight conditions at various mounting locations on the AH-1G helicopter.

DESCRIPTION

3. The test helicopter, serial number 67-15844, is a production AH-1G manufactured by Bell Helicopter Textron of Hurst, Texas. A detailed description of this helicopter is contained in the operator's manual (ref 9, app A).

4. The Honeywell UWVS system was designed and manufactured by the Government and Aeronautical Products Division of Honeywell, Inc., St. Louis Park, Minnesota. The UWVS model tested was a prototype unit that was originally used as a wind sensor for an improved fire control system on the AH-1G helicopter. This unit was made available to USAAEFA for flight evaluation at no cost to the Government.

5. The UWVS system tested consisted of the sensor and computer. A set of velocity meters was added for direct readout during the test program. The computer measures the total flow velocity and 3-orthogonal velocity components along the reference axis of the velocity sensor. A detailed description of the UWVS system and its theory of operation is presented in appendix B.

TEST SCOPE

6. The Honeywell UWVS system was tested by USAAEFA between 15 December 1975 and 30 January 1976. A total of 12 flight hours were conducted of which approximately 8 were productive test hours. Flight conditions were within the limitations contained in the safety-of-flight release (ref 10, app A) and the AH-1G operator's manual. Most flights were conducted at a mid center of gravity (cg) and an engine start gross weight of approximately 8500 pounds. Tests were conducted in both longitudinal and lateral flight, in ground effect (IGE), and out of ground effect (OGE), primarily during steady-state flight conditions. The sensor was mounted in five different locations on the aircraft to determine the effects of varying positions. The locations are shown in figure A.

TEST METHODOLOGY

7. On some low-airspeed tests the Honeywell UWVS system was calibrated by reference to another low-airspeed system which was previously calibrated by the pace car calibration technique. On other tests, a calibrated fifth wheel attached to the pace car was used to measure ground speed along the flight path. Ground speed was corrected for prevailing winds to obtain reference airspeed information. The aircraft was held parallel to the path of the pace car for forward and rearward calibrations and held perpendicular to the path of the pace car for lateral calibrations. Ambient wind was recorded on each data run from anemometers on a 60-foot tower. Data were recorded in winds no greater than 6 knots.

8. The high-speed data (above 40 knots) were referenced to the calibrated test boom system. Angle of attack and sideslip were measured with boom-mounted flow vanes. The angle of attack was corrected for position error obtained during the boom calibration. Angle-of-attack effects were determined by holding various rates of climb and descent at a constant airspeed.

UWVS	HELICOPTER BODY STATIONS		
Sensor Location	Fuselage Station	Butt Line	Waterline
1 (test boom)	-37	0	40
2 (sail mount)	186	-32	108
3 (rotor hub)	184	0	170
4 (fwd canopy)	104	0	108
5 (aft canopy)	121	0	109

Note: In position no. 1, the sensor was aligned with the test boom; in all other positions, the sensor was aligned with the helicopter reference axis system.

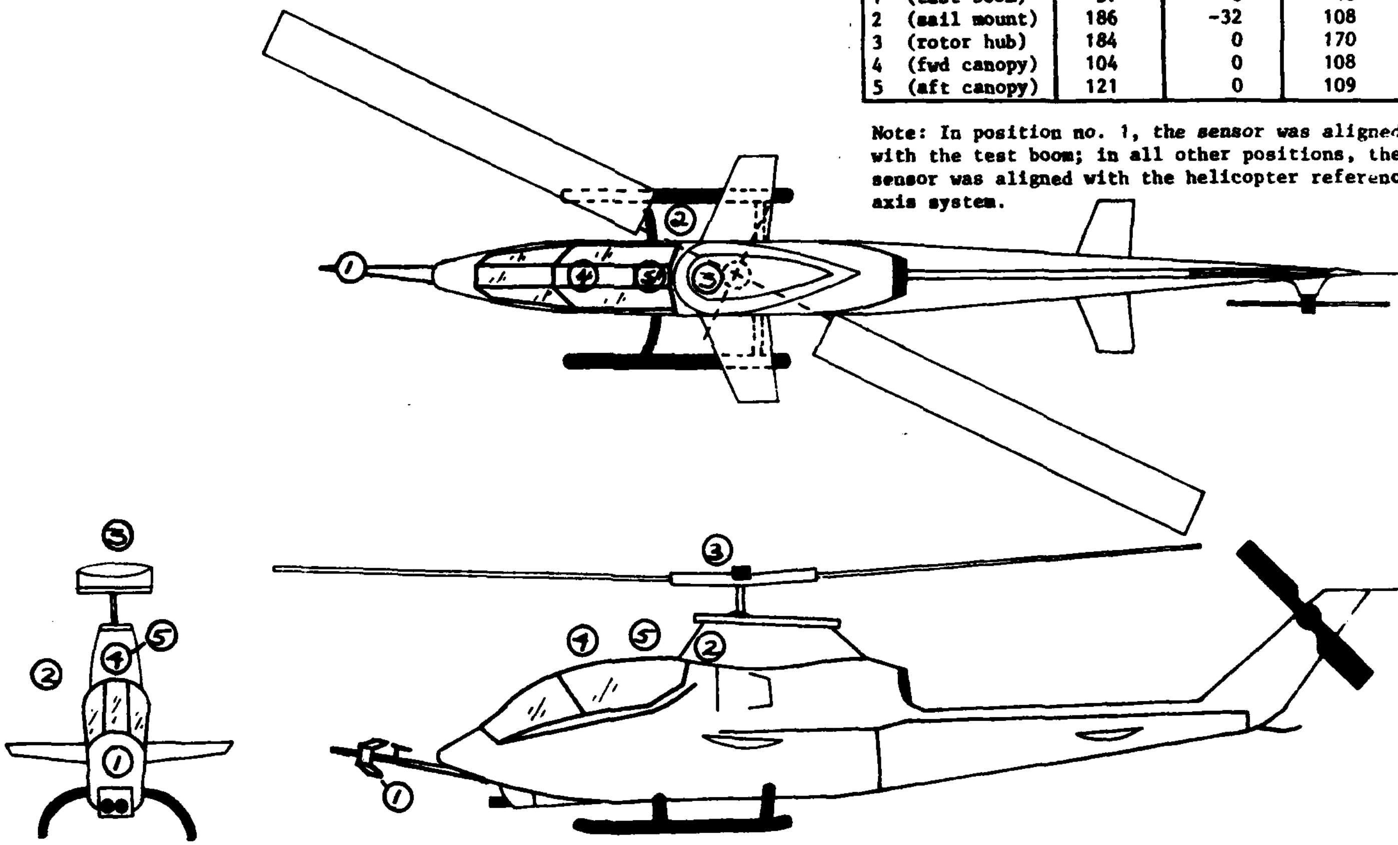

Figure A. Honeywell UWVS Sensor Test Locations on the AH-1G.

RESULTS AND DISCUSSION

GENERAL

9. The Honeywell UWVS system response was linear in forward flight when the sensor was free of the rotor downwash effects, although each sensor location had slightly different position errors. Under these flight conditions, the UWVS system was linear and repeatable in determining the flow direction in terms of angles of attack and sideslip. In rearward and lateral flight probe structure turbulence and/or rotor wake turbulence contributed to nonlinear or aperiodic saturation of the system response. The total temperature probe (which was aligned with the forward axes) introduced error due to inadequate airflow in some lateral and rearward flight or still air conditions.

10. Additional low-speed data obtained with the UWVS system mounted on a calibrated pace vehicle indicated that satisfactory performance was obtained for the forward (+WX) and downward (+WZ) velocity components. However, the rearward (-WX), upward (-WZ), and lateral (±WY) velocity components were found to be significantly off the true value.

SYSTEM PERFORMANCE IN FORWARD AND REARWARD FLIGHT

11. The performance of the UWVS system in forward and rearward flight with the sensor in five different locations is presented in figures 1 through 5, appendix D. The UWVS longitudinal component was linear in forward flight when the sensor was free of the rotor downwash effects. Each sensor location had a slightly different position error. The repeatability of the true airspeed system in forward flight is shown in figure 1, which presents three flights at different flight conditions at the same probe location. Below 10 knots true airspeed (KTAS) the sensor was operating within the rotor downwash and the averaged output velocity was essentially constant until a rearward airspeed exceeding 10 KTAS was obtained. At airspeeds greater than 10 KTAS rearward, the average data were nearly linear, but had significantly more variation than the forward flight data. In forward flight above 5 KTAS the indicated lateral velocity was accurate but was somewhat erratic (as shown in figure 1) when operating in the rotor downwash.

12. Figures 2, 4, and 5, appendix D, show the effects of operating the sensor at other locations within the rotor downwash. A transition region from the rotor wash to free-stream conditions is evident on each figure. This transition is similar to that obtained on other low-airspeed systems previously tested (refs 1 through 6, app A). Obstruction of the airflow around the sensor supports and fuselage appeared to cause some irregularity of the longitudinal component in rearward flight in all sensor locations. The sail mount position data (fig. 2, app D) show a lateral velocity error in high-speed flight, and the canopy mount location (figs. 4 and 5) shows a lateral velocity error in low-speed flight.

13. Figure 3, appendix D, shows the performance of the sensor when mounted above the rotor hub where it was free of direct downwash effects. Due to the geometry of the sensor unit, the velocity probes were located 18 inches forward of the mast, where local flow conditions may have contributed to the 8-KTAS position error from hover to 132 KTAS. The offset location and support structure may have contributed to the nonlinear and somewhat erratic data in rearward flight. The sensor was also mounted with its longitudinal axis aligned 2.5 degrees to the left of the aircraft axes, which accounts for the linear lateral error in figure 3.

SYSTEM PERFORMANCE IN LATERAL FLIGHT

14. The performance of the UWVS system in lateral flight with the sensor at five different locations is presented in figures 6 through 11, appendix D. In general, the lateral airspeed components were repeatable but were not linear with respect to true airspeed except when mounted above the rotor hub. When mounted on the fuselage, the rotor downwash and tip vortices in the wake boundary had a pronounced effect on the lateral data. The transition from the rotor downwash to free-stream was much different in right sideward flight than left. Figures 6, 7, 9, and 10 indicate that the transition in right sideward flight occurs at 15 to 20 KTAS, over an approximate 10-KTAS velocity range, and is similar to the forward flight transition characteristics. However, in the probe locations shown in figures 7, 9, and 10 for left sideward flight, the sensor indicated the presence of extremely strong flow conditions where total velocities of over 100 KTAS were measured. Depending on the probe's location, these conditions were encountered at lateral velocities of 10 to 30 KTAS, making the lateral component essentially unusable at airspeeds over 20 KTAS. Geometric considerations indicate that mounting the sensor as near the mast as possible would produce the widest range of usable lateral airspeeds. The longitudinal velocity component cross-coupling was most significant in position No. 2 (fig. 7).

15. As shown in figure 8, appendix D, the best results were obtained in lateral flight when the sensor was mounted above the rotor hub. However, above 25 KTAS to the left, the system indicated an abrupt flow direction change. The flow condition might be improved if the sensor were designed to be mounted on the mast center line, since other low-airspeed systems which were mounted on the center have not shown significant variation of flow direction in lateral flight (refs 2, 3, and 5, app A). Based on the referenced data, center line mounting should also reduce the longitudinal position error.

SYSTEM DIRECTIONAL PERFORMANCE

16. The capability of the UWVS system to measure flow direction in terms of the angle of attack and sideslip when mounted in positions No. 1 and 3 was determined by comparing its output to the nose boom vanes. Figures 11 and 12, appendix D, show the angle of attack comparison for the respective locations. The UWVS system angles were computed from the output velocity components and

were linear but slightly offset from the true value. In the nose boom location, the 2-degree displacement at zero angle of attack could have been caused by a slight misalignment between the boom and the Honeywell sensor. The angle of attack and sideslip slope error offsets should be correctable. The largest error occurred in descent when the sensor was mounted above the rotor hub (fig. 12) where the free-stream flow is upward through the rotor, causing the system to read approximately 9 degrees low at a true value of 13 degrees.

17. Figures 13 and 14, appendix D, show the angle of sideslip comparison which was obtained by yawing the helicopter at various angles up to ±20 degrees at a constant 65 knots calibrated airspeed (KCAS). The Honeywell data were linear, but the slope was slightly offset from the line of zero error and should be correctable.

SYSTEM CALIBRATION ON GROUND PACE VEHICLE

18. In addition to the flight data, a set of low-speed data was obtained by mounting the UWVS system on a ground vehicle with a calibrated anemometer. Figures 15 through 17, appendix D, present the results of this test for the longitudinal, lateral, and vertical axes, respectively. This test indicated that the system performance was satisfactory for forward (+WX) and downward (+WZ) components, but the rearward (-WX), upward (-WZ), and lateral (±WY) components were apparently changed in gain or limited as to range. Lateral performance of the probe mounted on the pace car (fig. 16) showed system instabilities and limited lateral velocity measurements for input lateral velocities in excess of ±25 knots, which was similar to the rotor mast location results. These instabilities indicate a probe self-generated turbulence and source of signal noise that limited the system performance and stability at large lateral velocities.

COCKPIT DISPLAY

19. The cockpit display provided with the prototype UWVS system consisted of three separate velocity meters calibrated in units of meter per second, and was not intended for use on an operational aircraft. For crewmember use the information of airspeed, angle of attack, and angle of sideslip must be displayed in a simple, straightforward manner.

CONCLUSIONS

GENERAL

20. The prototype Honeywell UWVS system measured true airspeed and flow direction in a repeatable and accurate manner when operating in forward flight and free of rotor downwash effects in all locations tested. The best performance was obtained with the system mounted above the rotor mast. When mounted below the rotor, significant nonlinearity and system error occurred, due to rotor wake flow and self-induced turbulence over the sensor, producing unusable results in some flight conditions. The nonlinearity in the lateral and rearward velocity components was also verified by low-speed data obtained on a ground pace vehicle. If these problems are corrected, the UWVS system could be an effective three-dimensional velocity sensor which could be calibrated to provide accurate helicopter velocity.

SPECIFIC

21. In still air conditions inadequate airflow through the temperature probe introduced system errors in the true airspeed calculations (para 9).

22. The Honeywell UWVS system provided linear, repeatable, and accurate wind velocity and direction information in forward flight when free of rotor downwash effects (paras 11, 16, and 17).

23. When the UWVS sensor was oriented within the rotor downwash, the transition characteristics and data discontinuity were similar to other low-airspeed systems previously tested (para 12).

24. The sensor lateral velocities were generally repeatable. Above the rotor mast the effective lateral velocity ranged from 25 knots left to 35 knots right, but in other locations tested, the usable airspeed calibrations were limited to airspeeds of 20 KTAS or less (para 14).

25. The best performance was obtained with the system mounted above the rotor mast (para 15).

RECOMMENDATIONS

26. The UWVS temperature probe should be redesigned to provide proper temperature information in all flight regimes (para 9).

27. Consideration should be given to development of a single cockpit instrument which displays airspeed and direction information (para 19).

28. The nonlinear characteristics of the lateral, rearward, and downward velocity components should be improved.

APPENDIX A. REFERENCES

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11. Paper, F. J. Ferrin, Honeywell, Inc., and M. Yurescko, Frankford Arsenal: "Ultrasonic Wind Vector Sensor." Presented at technical conference on "The Effects of Helicopter Downwind on Free Projectiles," US Army Aviation Systems Command, St. Louis, Missouri, 12 to 14 August 1975.

APPENDIX B. SYSTEM DESCRIPTION AND THEORY OF OPERATION

INTRODUCTION

1. Fire control system solutions for reliable rocket delivery from helicopters require that the effect of the relative wind be determined accurately. The ability to sense the relative wind on a rotary wing aircraft is difficult because of the inherent large variations in wind magnitude and direction. A sensor is needed which will be sensitive and stable at low airspeed with large off-axis components, as well as giving satisfactory performance at high airspeeds. The UWVS system, shown in photo 1, was developed to provide an accurate measure of the relative wind while utilizing no moving parts, giving linear sensitivity over the entire airspeed range, and responding to rapid changes in wind magnitude and direction. The UWVS operates on a principle involving ultrasonic signal transmissions through the moving air mass (ref 11, app A).

FUNCTIONAL CONCEPT

2. Defining the wind velocity components requires a geometric arrangement of *three ultrasonic transmission paths* deployed in the airflow. From this, three equations can be derived to express the velocity components as functions of the measured transmission times along the paths. Figure 1 illustrates the relationship of the wind velocity components to the standard aircraft angles of attack and sideslip. Also shown are the three transmission *paths and the associated transit* times, t_1, t_2, and t_3. The temperature sensor is needed to compute the wave velocity in air as a function of temperature. The transmitters are simultaneously pulsed and at a later time, typically 200 to 300 microseconds, the wave arrives at the receivers. Figure 2 shows the vector relationships from which the equations are derived.

3. The resulting equation for one transmitter/receiver pair is shown in figure 2. As can be seen, it contains three unknowns, the W_X, W_Y, W_Z wind vectors, and the measured transit time for the particular path. By writing the equations for the other two transmitter/receiver pairs as a function of their respective transit times, three equations with the three unknown vectors result. After rearranging the equations, the expressions shown in figure 4 result. These are not of a closed form because the vectors are a function of W and therefore must be solved by iterative or feedback methods. With zero relative wind velocity, the three transit times will be identical and equal to the ultrasonic wave transit time at the particular temperature (25°C) the times would be as follows:

4. With a relative wind along the X axis only, the times are also equal, but now increase in value for forward aircraft motion. For relative wind speeds up to 100 meters per second, the times increase by about 30 percent. For relative

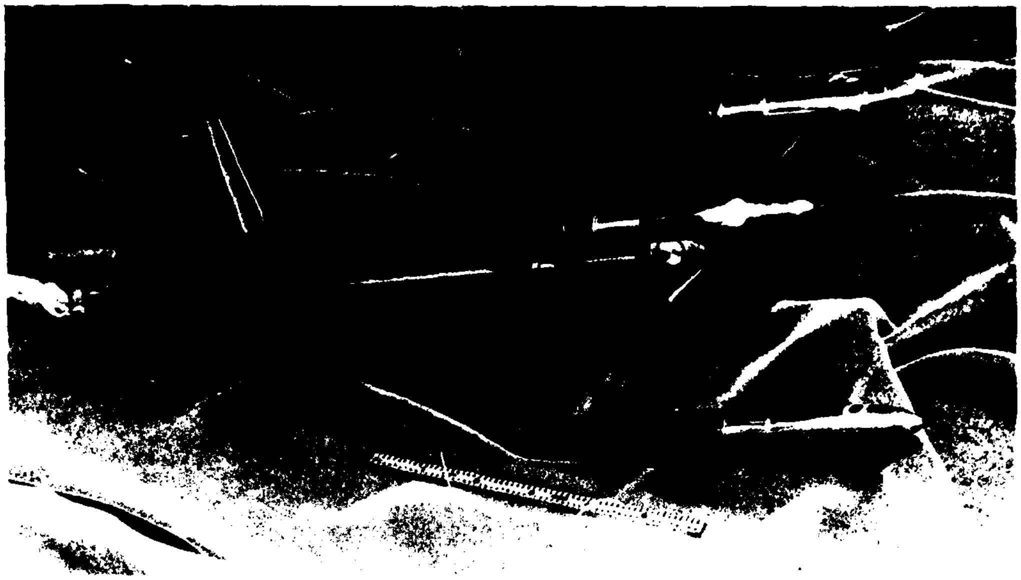


Photo 1. Ultrasonic Wind Vector Sensor (UWVS).

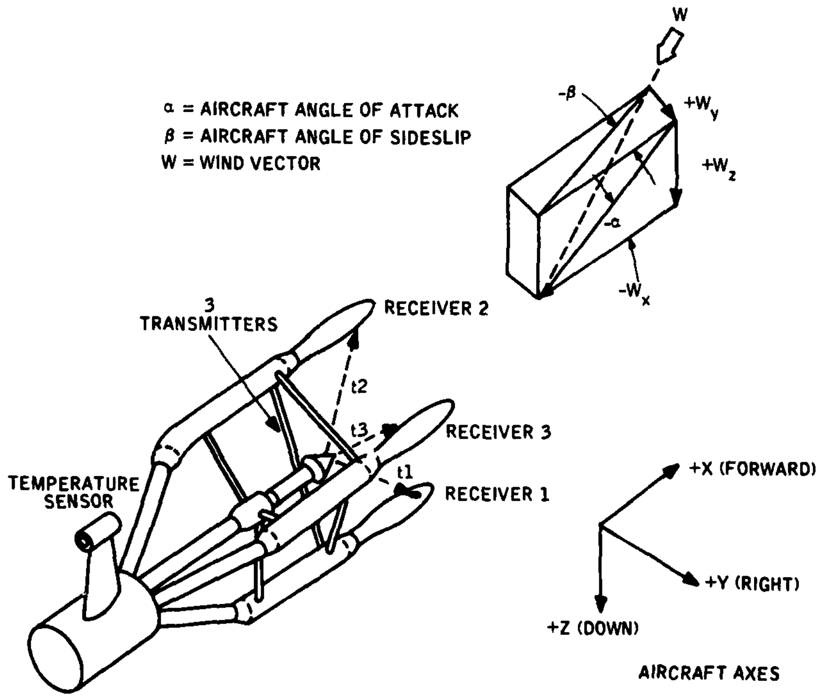
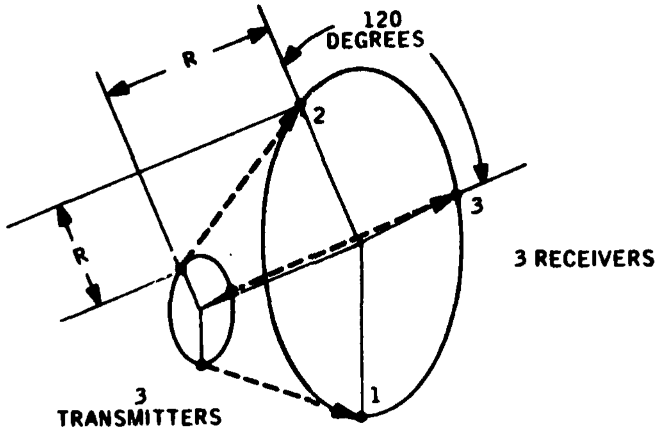
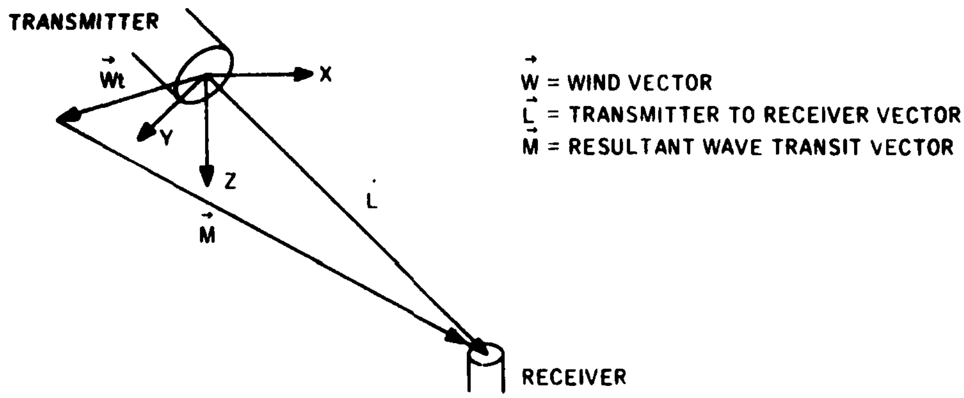


Figure 1. Wind Vector Definition.



UWVS GEOMETRY



VECTOR DEFINITION

$$\vec{M} = \vec{L} - \vec{W}t$$

$$\vec{W} = w_x\hat{i} + w_y\hat{j} + w_z\hat{k}$$

$$\vec{L} = \ell_x\hat{i} + \ell_y\hat{j} + \ell_z\hat{k}$$

$$|\vec{M}| = Ct$$

C = SPEED OF ULTRASONIC WAVE

$$(\ell_x - w_x t)^2 + (\ell_y - w_y t)^2 + (\ell_z - w_z t)^2 = C^2 t^2$$

Figure 2. UWVS Geometry and Vector Definition.

$$W_x = \frac{-R}{3}\left(\frac{1}{t_1}+\frac{1}{t_2}+\frac{1}{t_3}\right)+\frac{\left(C^2-W^2\right)}{6R}\left(t_1+t_2+t_3\right)$$

$$W_y = \frac{R\sqrt{3}}{3}\left(\frac{1}{t_2}-\frac{1}{t_3}\right)-\frac{\left(C^2-W^2\right)\sqrt{3}}{6R}\left(t_2-t_3\right)$$

$$W_z = \frac{-R}{3}\left(\frac{2}{t_1}-\frac{1}{t_2}-\frac{1}{t_3}\right)+\frac{\left(C^2-W^2\right)}{6R}\left(2t_1-t_2-t_3\right)$$

$$W^2 = W_x^2+W_y^2+W_z^2$$

$$C^2 = C_0^2\left(\frac{T+273}{298}\right)$$

C_0 = 346.192 METERS PER SECOND

Figure 3. UWVS Equations.

wind in an arbitrary direction, the three times will be different in value. In general, the times can be considered as quantities which vary by a percentage around the still air value. Because of this, the equations were rewritten to provide simplified computation which is dependent on difference times. Using numerical approximation methods, the equations in figure 4 will result. The computation involves time differences around the still air transit time at 25°C and temperature differences around 25°C. These equations have been shown to provide results which contribute negligible mathematical errors.

MECHANIZATION

5. The UWVS was mechanized as shown by the functional diagram illustrated in figure 5. This is part of a 2.75-inch rocket delivery system. The transmitters utilized are piezoelectric transducers resonant at 75 kilohertz, while the receivers are wide band-width ceramic microphones with response out to 400 kilohertz. These are isolation mounted in a lightweight tubular aluminum structure (photo 1). The temperature sensor is a platinum element, thermally isolated from the structure. The sensor unit also contains a temperature sensor amplifier and three receiver preamplifiers. The transmitter drive, timing logic, pulse detection circuitry, and the electronics used to solve the equations are contained for the time being in a separate electronics unit.

6. Either a digital processor can be utilized for the solutions or analog methods can be employed. Because of their simplicity, the equations in the present mechanization are solved using a unique analog multiply/divide technique. The accuracy of the circuitry is sufficient to contribute negligible error to the wind vector determination.

PERFORMANCE ANALYSIS

7. Performance analysis indicates that there are six primary areas that can influence the UWVS accuracy. A summary of each of these effects is presented below.

Transducer Location

8. This is associated with the location of a particular receiver with respect to its transmitter. Calibration is accomplished in a straightforward manner by merely positioning the receiver booms, with zero wind, until the transmit time is equal to the theoretical value for that temperature and the specified value of transmitter/receiver distance. Doing this to within ±0.1 microsecond has proven to be satisfactory and is readily accomplished.

$$W_x = S_1W^2 + \left[S_2 + S_3W^2 + S_4\,(T-25)\right]\left[t_1 + t_2 + t_3 - 3t_0\right] + \left[S_5\,(T-25) + S_6\,(T-25)^2\right]$$

$$W_y = Q_1\left[Q_2 + Q_3\,W_x + Q_4\,(T-25)\right]\left[t_2 - t_3\right]$$

$$W_z = Q_5\left[Q_2 + Q_3\,W_x + Q_4\,(T-25)\right]\left[2t_1 - t_2 - t_3\right]$$

$$W^2 = W_x^2 + W_y^2 + W_z^2$$

- $S_1 \rightarrow S_6$ AND $Q_1 \rightarrow Q_5$ ARE CONSTANTS
- t_1, t_2, AND t_3 = TRANSIT TIMES
- t_0 = REFERENCE TIME AT W = 0 AND T = 25°C
- (T-25) = TEMPERATURE - 25°C

Figure 4. Simplified Equations.

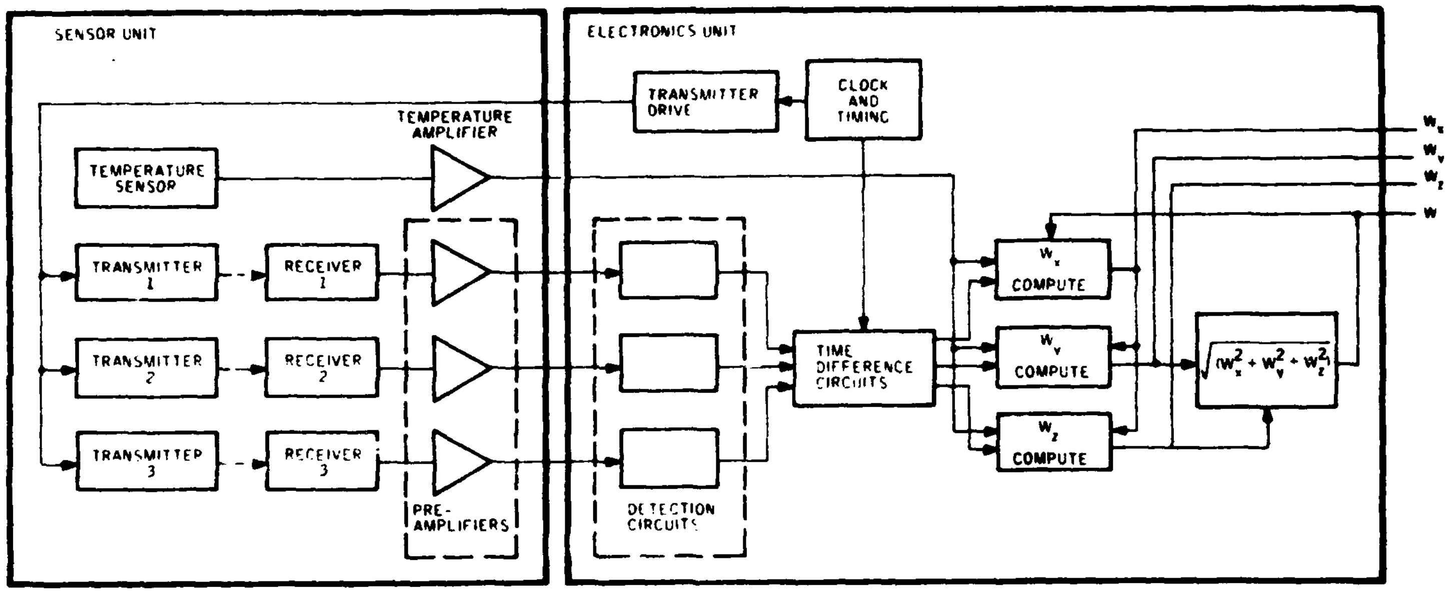


Figure 5. UWVS Functional Block Diagram.--

Aerodynamic Effects

9. Inserting any finite volume into an airstream modifies the flow to some extent. In the case of the UWVS, tests have shown that the equations require only a fixed scaling change to minimize the effect for the sensor geometry used. It should be noted that, depending on the sensor mounting location, the flow around the aircraft structure will change the sensor measurements. This obviously is not a sensor-related error, because any sensor used can only be expected to measure the actual flow over it. It is appropriate, however, to compensate for mounting location flow irregularities in the wind vector computation. The UWVS mechanization includes terms in the equation processing which can provide compensation so that the computed wind vectors are an accurate measure of the aircraft motion through the air mass.

Signal Noise

10. The limiting noise source in the UWVS occurs as the flow across the sensor becomes turbulent at high airspeeds. With the present structure, the noise from local air turbulence becomes significant at wind velocities over 200 knots, which is above practical maximum helicopter airspeeds. The effect of this noise is to cause jitter in the computed wind vector values.

Installation Alignment

11. Alignment of the UWVS to the aircraft reference frame is accomplished during aircraft leveling and alignment. Because of the geometry, a level can be used for *two axes and a boresight tool for the other axis.*

Environmental Conditions

12. Temperature, altitude, and vibration tests have been conducted on the UWVS by Honeywell. Temperature tests from -49°F to +140°F have shown no significant effect on performance of electronic equipment. Altitude tests show ultrasonic signal attenuation as expected, with 6 decibels per 18,000 feet being measured. The signal attenuation, however, did not affect operation. Vibration tests show that any resonances are well above those input frequencies experienced on rotary wing aircraft. Flight tests to date on an Army Cobra helicopter also indicate that no structural or functional problems exist.

Electronic Circuitry

13. Another contribution to UWVS performance is associated with the pulse detection and time difference circuitry. The stability of these functions has been measured by Honeywell and found satisfactory. After the receiver boom position calibration has been performed, the time difference values as determined electronically do not change enough to influence overall performance.

PERFORMANCE TESTS

14. The UWVS has been evaluated in two wind tunnel facilities. Early developmental testing was accomplished in a Honeywell wind tunnel with a small test section. During this phase of the program, various structural shapes, transmitter types, receiver types, and transducer orientations were evaluated which led to the present configuration. Development continued with sensor performance testing under varying wind magnitudes and directions. More recently, testing was accomplished in a larger facility having a 7 by 10-foot test section (Ling Temco Vaught low-speed wind tunnel, Dallas, Texas). Measurements were made with tunnel wind velocities up to 200 knots. Flight conditions having angles of attack and sideslip were simulated by rotating the UWVS 90 degrees in the tunnel. This extreme orientation allowed evaluation under simulated helicopter downwash at hover. After conclusion of the USAAEFA flight test program, additional tests of the UWVS were conducted at the Honeywell wind tunnel. Results of this testing are included as appendix E.

APPENDIX C. TEST INSTRUMENTATION

1. The following parameters were recorded on board the test helicopter on magnetic tape and were also capable of telemetry transmission.

Parameter	Normal Calibration Range
Time of day (B)[1]	Hours, min, sec, millisec
Engineer event (B)	Off/zero, on/128 counts
Run number counter (B)	Zero to 127 counts
Test boom altitude	1000 to 8000 feet
Test boom airspeed	20 to 140 KCAS
Outside air temperature (total)	-10 to 50°C
Angle of attack	-45 to +45 deg
Angle of sideslip	-45 to +45 deg
Rotor speed	250 to 350 rpm
Pitch attitude	-30 to +30 deg
Roll attitude	-60 to +60 deg
LASSIE II[2] sin alpha	zero to +1
LASSIE II cos alpha	-1 to +1
LASSIE II sin beta	-1 to +1
LASSIE II cos beta	-1 to +1
LASSIE II lateral airspeed	-40 to +40 KCAS
LASSIE II longitudinal airspeed	-40 to +130 KCAS
LASSIE II total velocity	Zero to 130 KCAS
UWVS[3] longitudinal airspeed	-50 to +200 KTAS
UWVS lateral airspeed	-50 to +50 KTAS
UWVS vertical airspeed	-50 to +50 KTAS
UWVS total velocity	Zero to 250 KTAS
LORAS[4] longitudinal airspeed	-50 to +150 KTAS
LORAS lateral airspeed	-50 to +50 KTAS

2. The following parameters were hand-recorded on the ground (when required):

Parameter	Normal Calibration Range
Wind speed (60-foot tower)	Zero to 35 KTAS
Wind direction (60-foot tower)	Zero to 360 deg
Pace vehicle speed	Zero to 50 KTAS
Pace vehicle heading	Zero to 360 deg

[1] B: Bilevel channel (all others zero to 5-volt DC analog).
[2] E-A Industrial Corporation low airspeed sensing equipment (LASSIE).
[3] Honeywell ultrasonic wind vector sensing system (UWVS).
[4] Pacer Systems low range airspeed system (LORAS).

Aircraft heading	Zero to 360 deg
Wind speed (pace vehicle)	Zero to 50 KTAS
Wind direction (pace vehicle)	Zero to 360 deg

3. The following parameters were displayed on the engineer panel.

Parameter	Normal Calibration Range
Time of day	Hours, min, sec
Run counter	Zero to 127 counts
Outside air temperature	-10 to 60°C
Test boom airspeed	15 to 140 KCAS
Test boom altitude	1000 to 8000 feet
UWVS longitudinal airspeed	Not calibrated
UWVS lateral airspeed	Not calibrated
UWVS vertical airspeed	Not calibrated

4. The following parameters were displayed on the pilot panel.

Parameter	Normal Calibration Range
Test boom altitude	1000 to 8000 feet
Test boom airspeed	15 to 140 KCAS
Angle of sideslip	±45 deg
Rotor speed (sensitive)	220 to -350 rpm
Rotor/output shaft speed (ship's)	Not calibrated
Engine torque pressure	Not calibrated
Compressor speed	Not calibrated
Exhaust gas temperature	Not calibrated
Aircraft heading (magnetic)	Not calibrated
LORAS II longitudinal airspeed	-30 to 60 KCAS
LORAS II lateral airspeed	-35 to 35 KCAS
LASSIE II longitudinal airspeed	Not calibrated
LASSIE II lateral airspeed	Not calibrated

APPENDIX D. TEST DATA

INDEX

FIGURE 1

AIRSPEED CALIBRATION IN FORWARD AND REARWARD FLIGHT

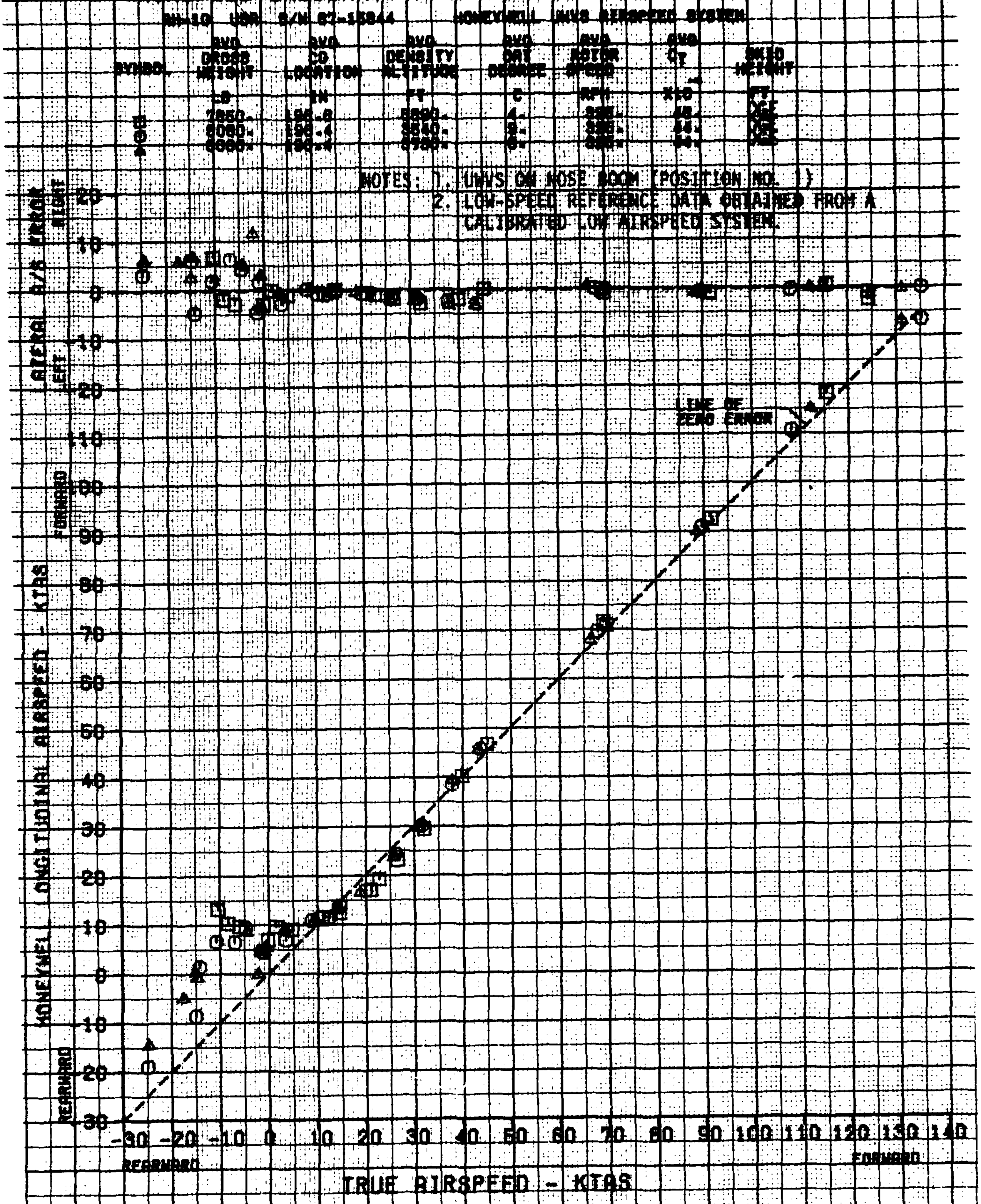


FIGURE 2

AIRSPEED CALIBRATION IN FORWARD AND REARWARD FLIGHT

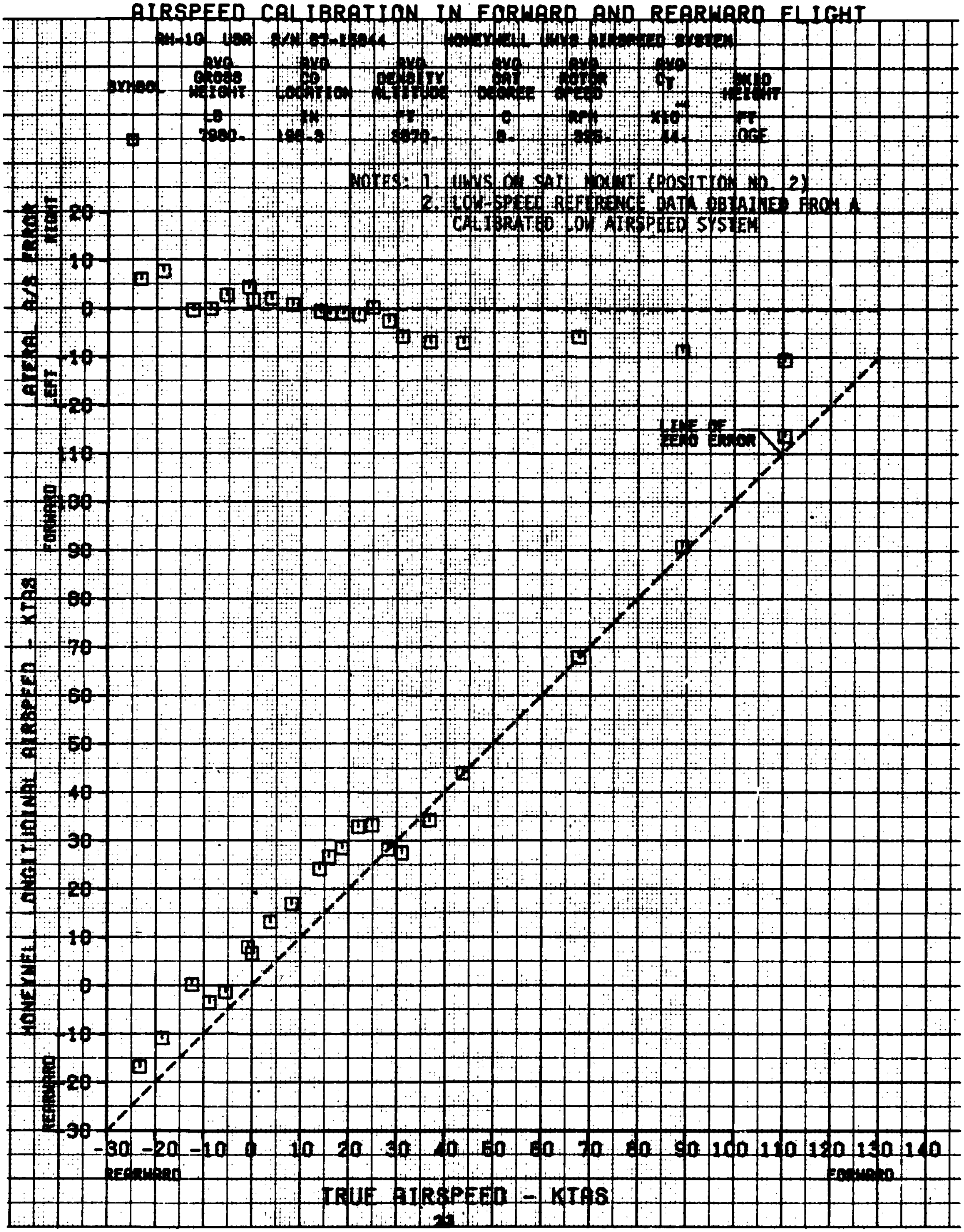


FIGURE 3
AIRSPEED CALIBRATION IN FORWARD AND REARWARD FLIGHT

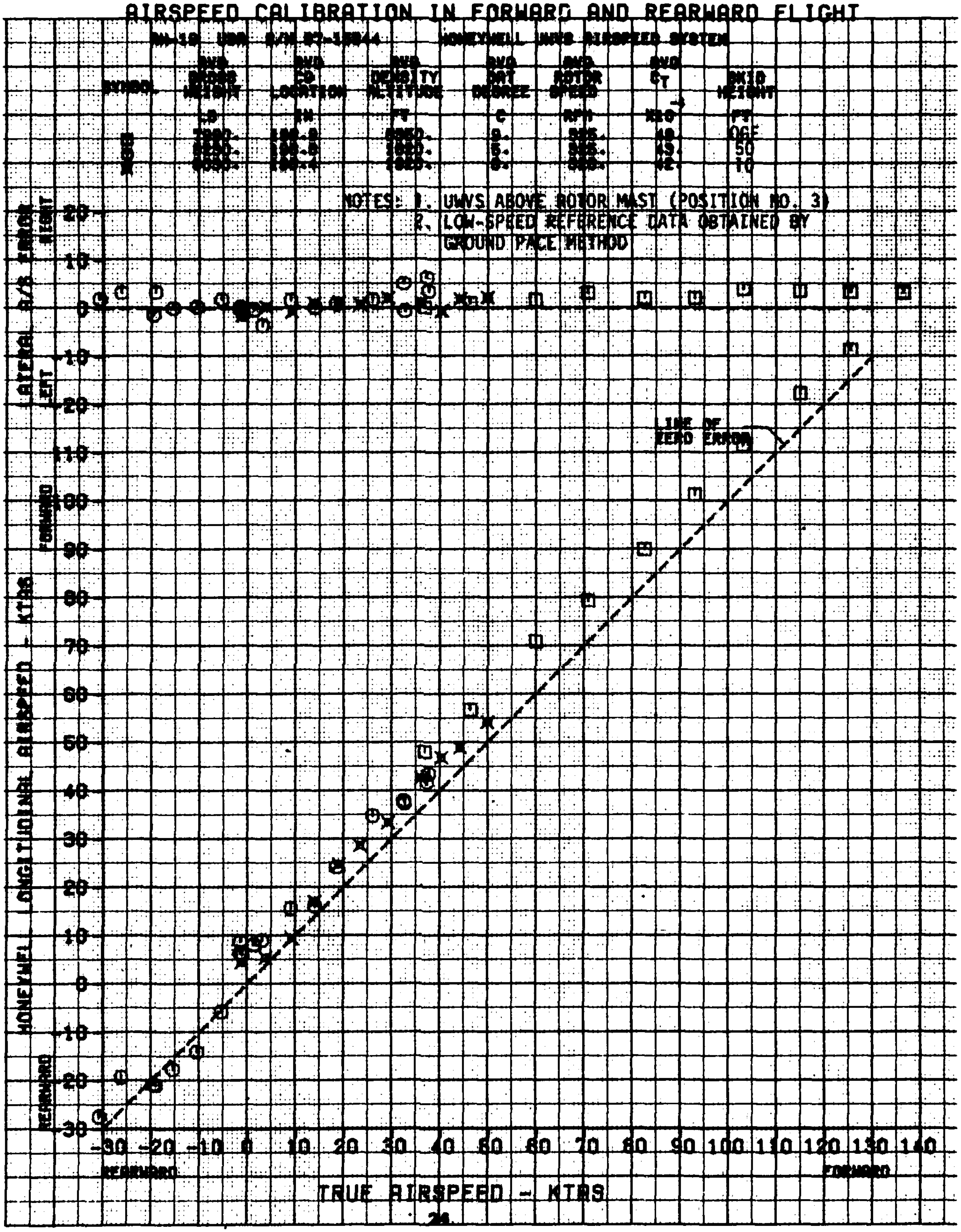


FIGURE 4
AIRSPEED CALIBRATION IN FORWARD AND REARWARD FLIGHT

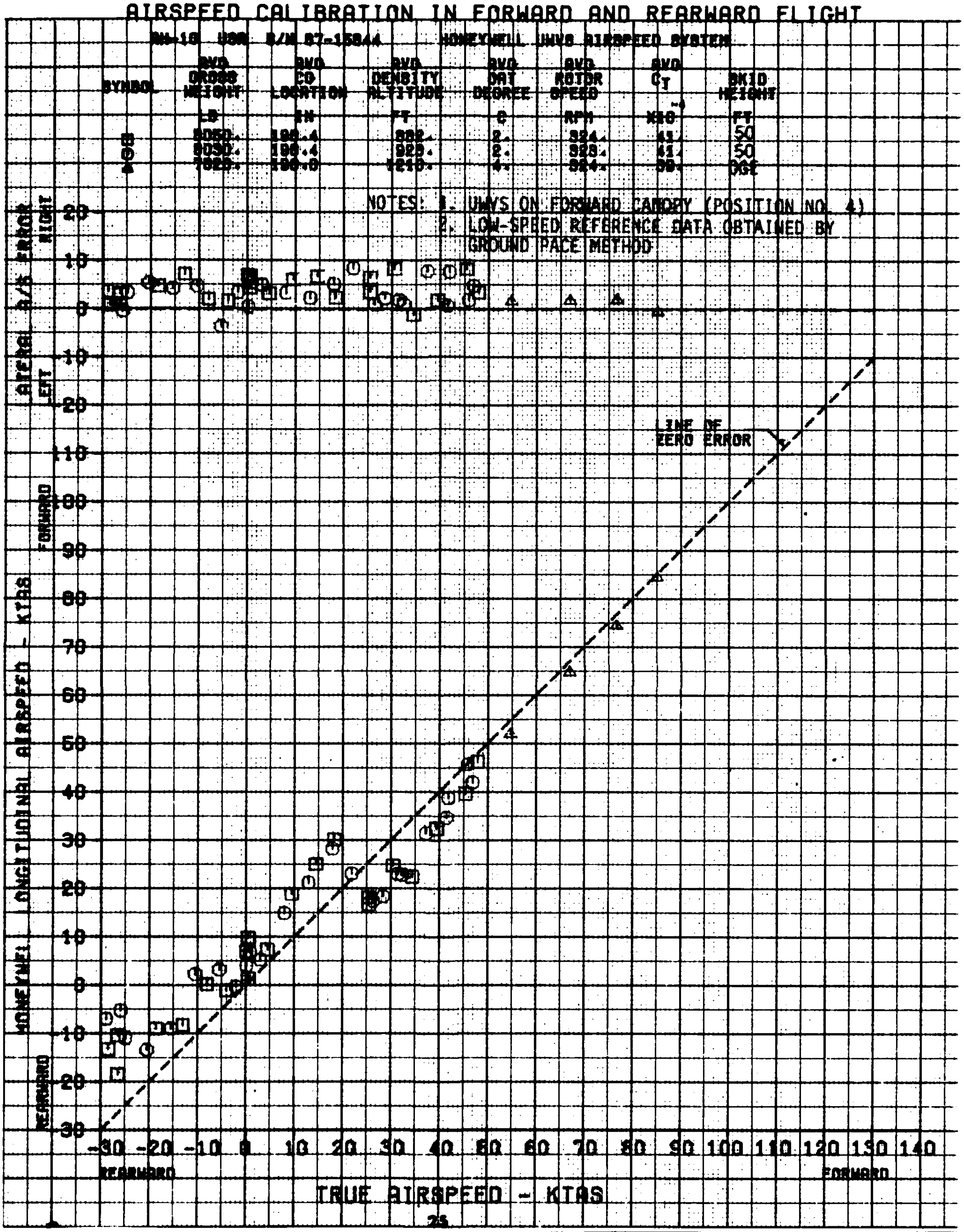


FIGURE 5

AIRSPEED CALIBRATION IN FORWARD AND REARWARD FLIGHT

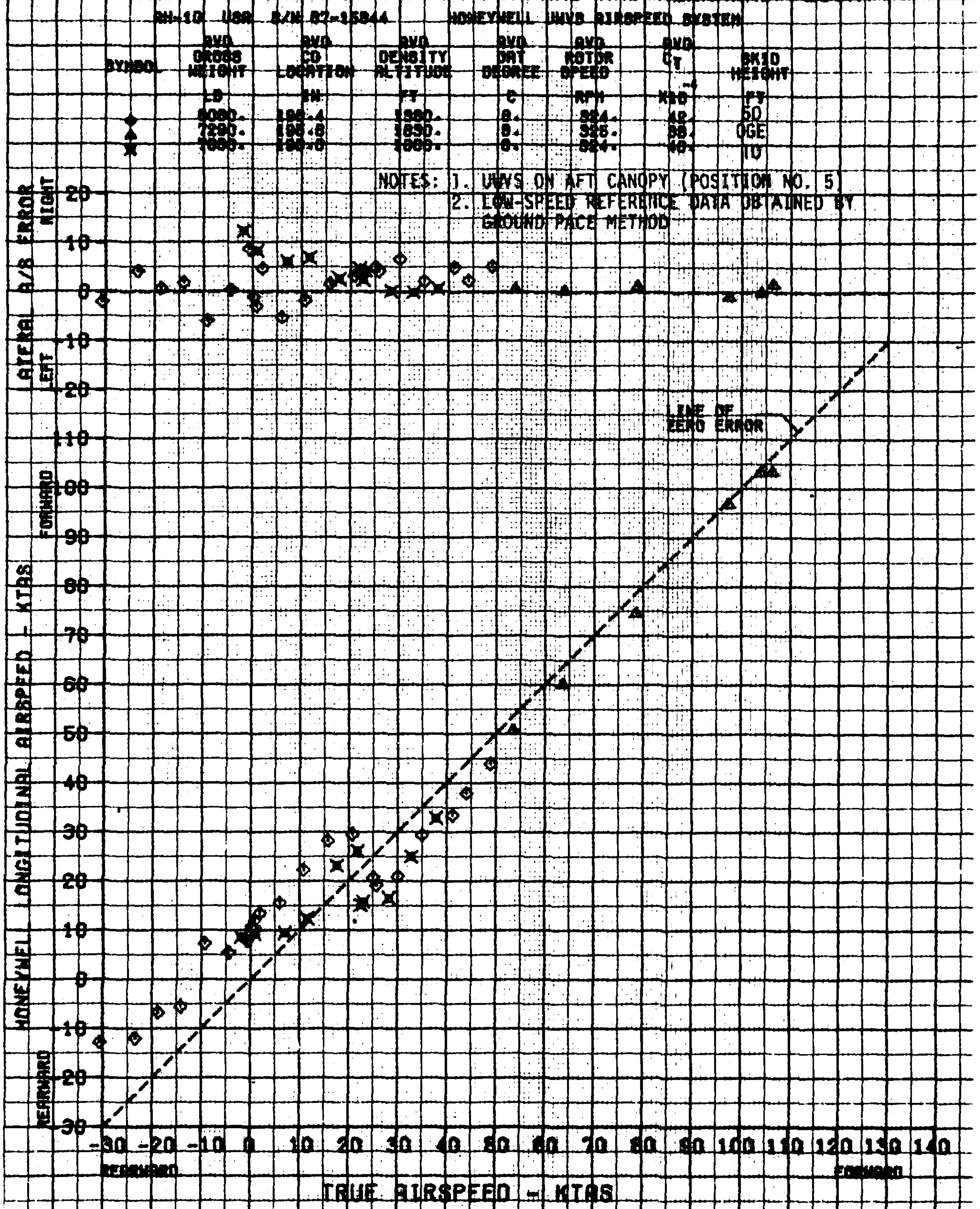


FIGURE 6
AIRSPEED CALIBRATION IN SIDEWARD FLIGHT

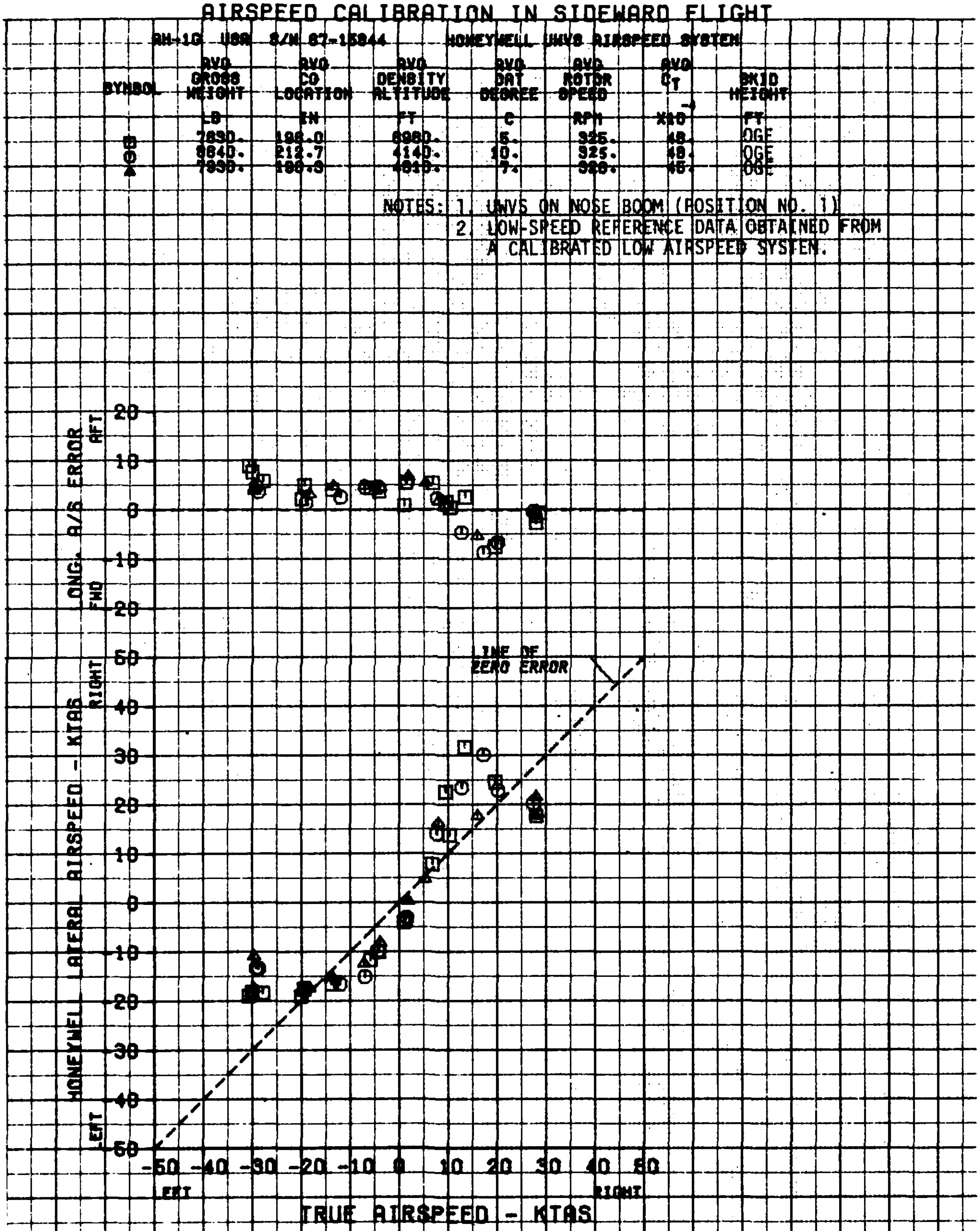


FIGURE 7
AIRSPEED CALIBRATION IN SIDEWARD FLIGHT

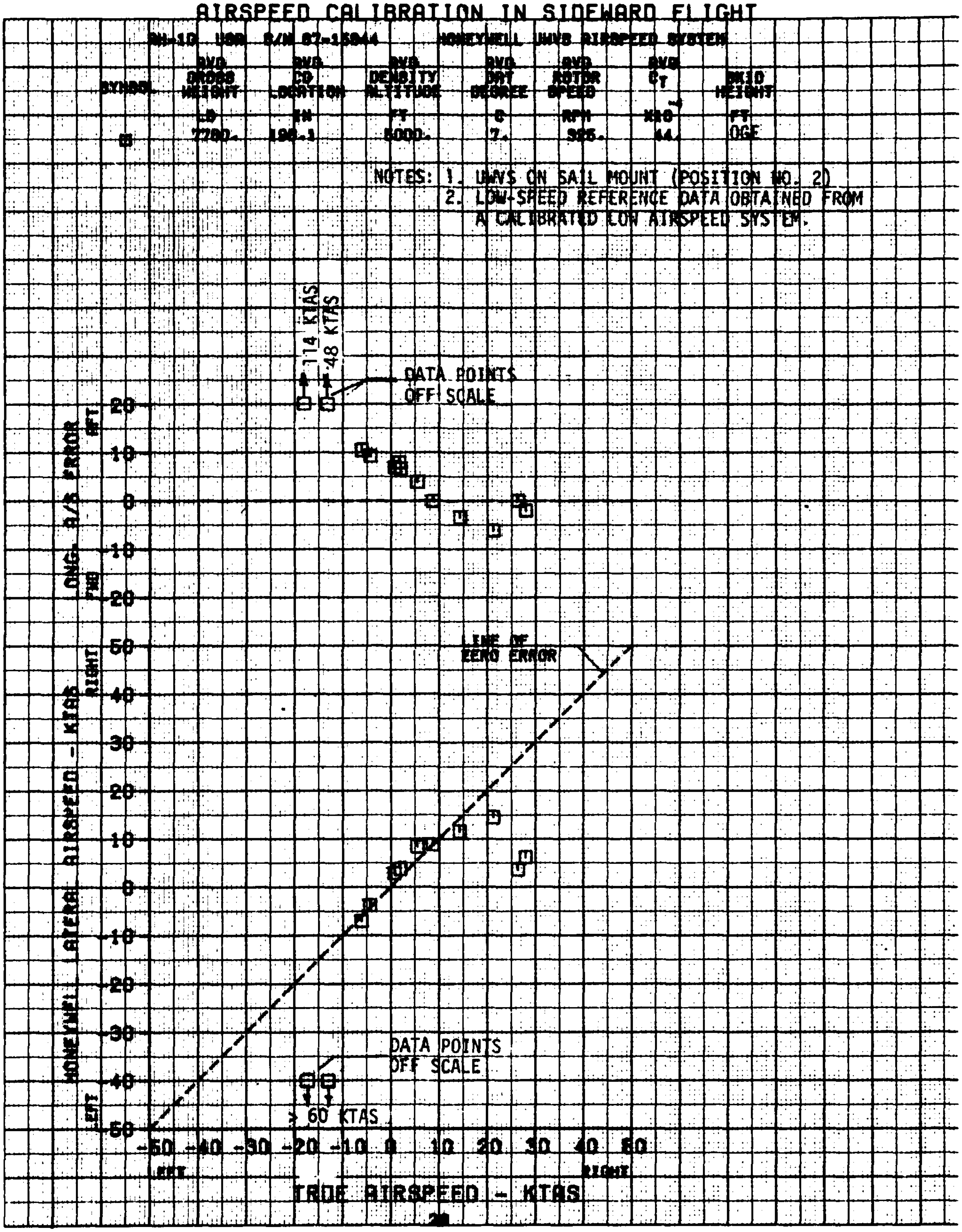


FIGURE 8

AIRSPEED CALIBRATION IN SIDEWARD FLIGHT

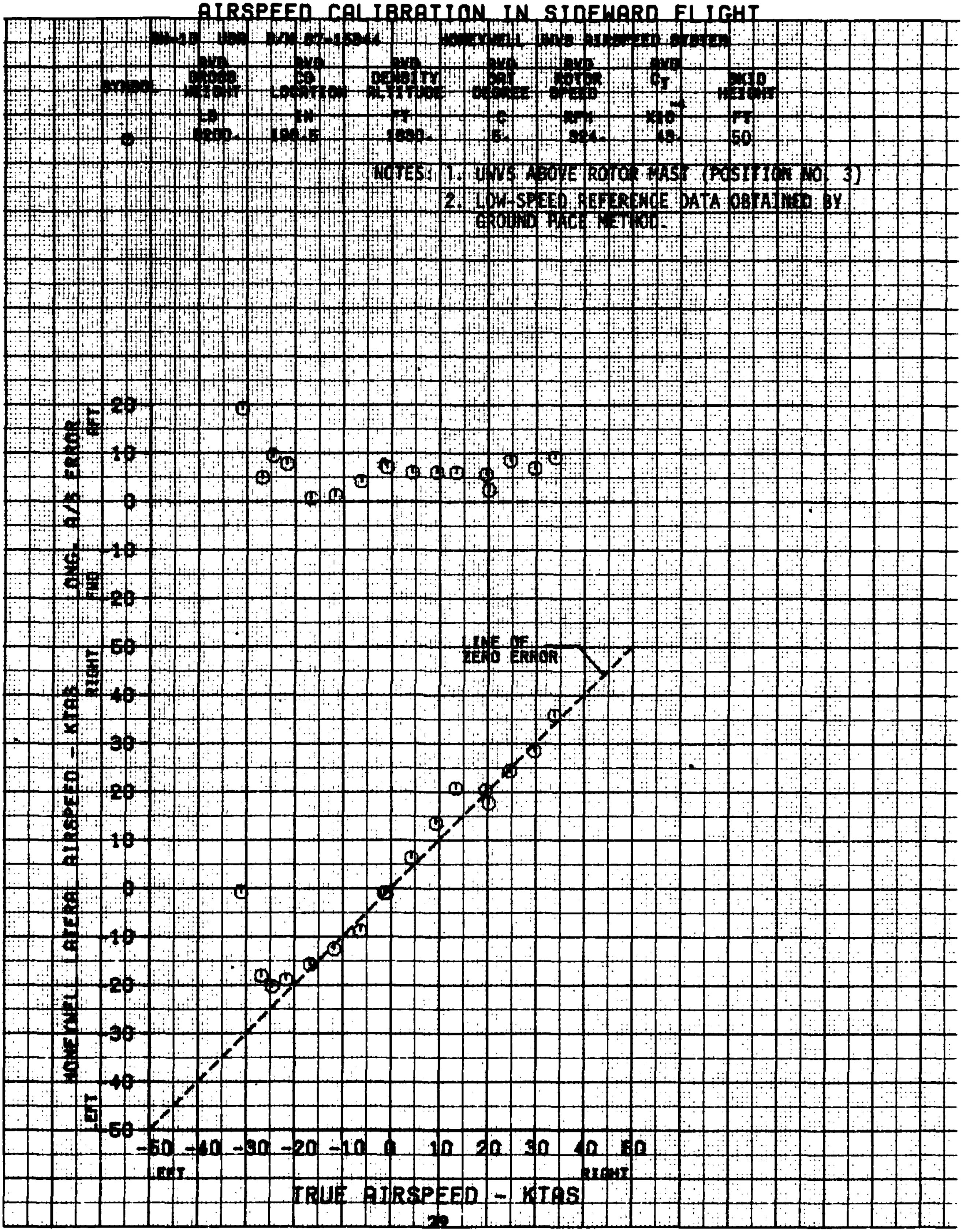


FIGURE 9

AIRSPEED CALIBRATION IN SIDEWARD FLIGHT

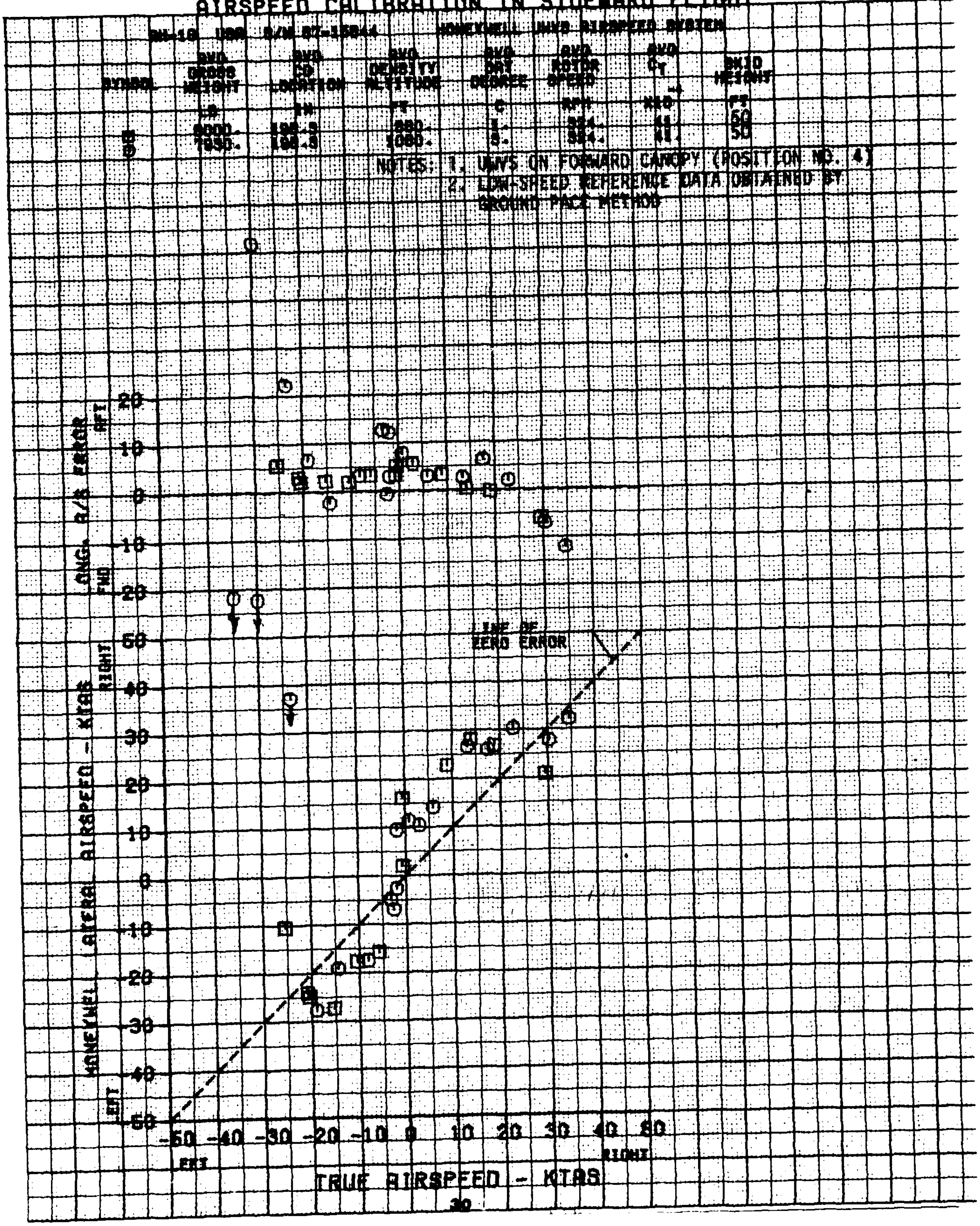


FIGURE 10

AIRSPEED CALIBRATION IN SIDEWARD FLIGHT

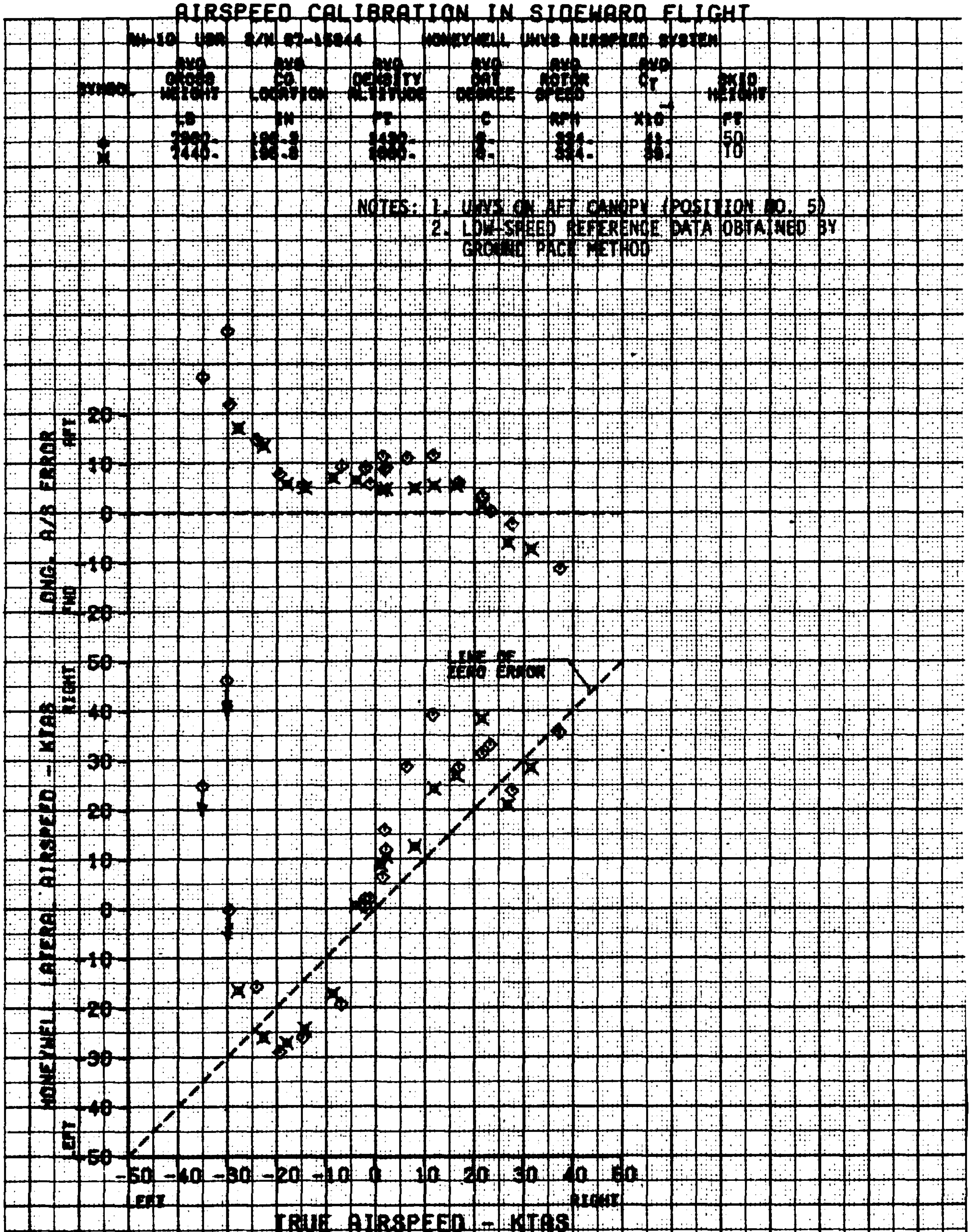


FIGURE 11

ANGLE OF ATTACK CALIBRATION

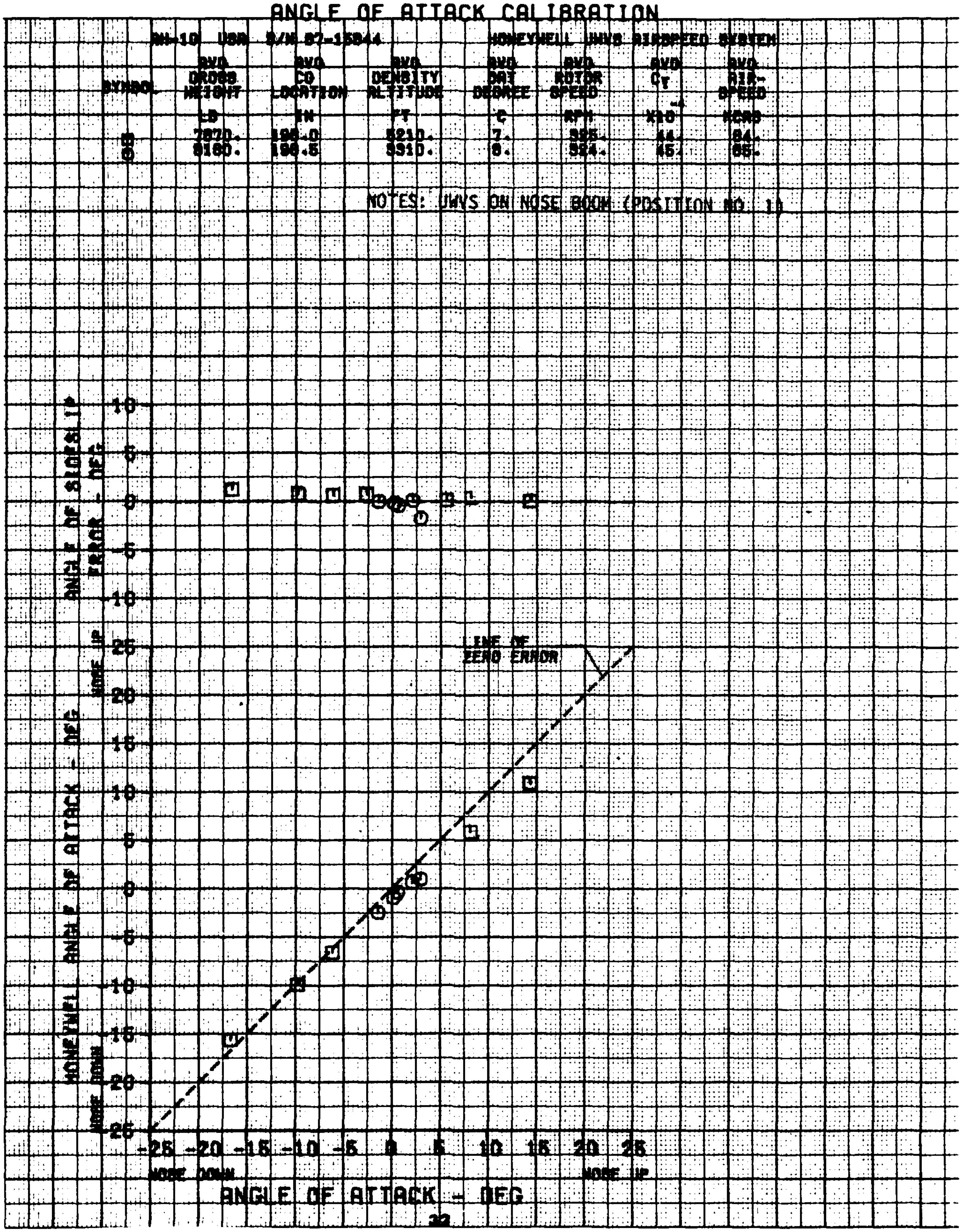


FIGURE 12
ANGLE OF ATTACK CALIBRATION

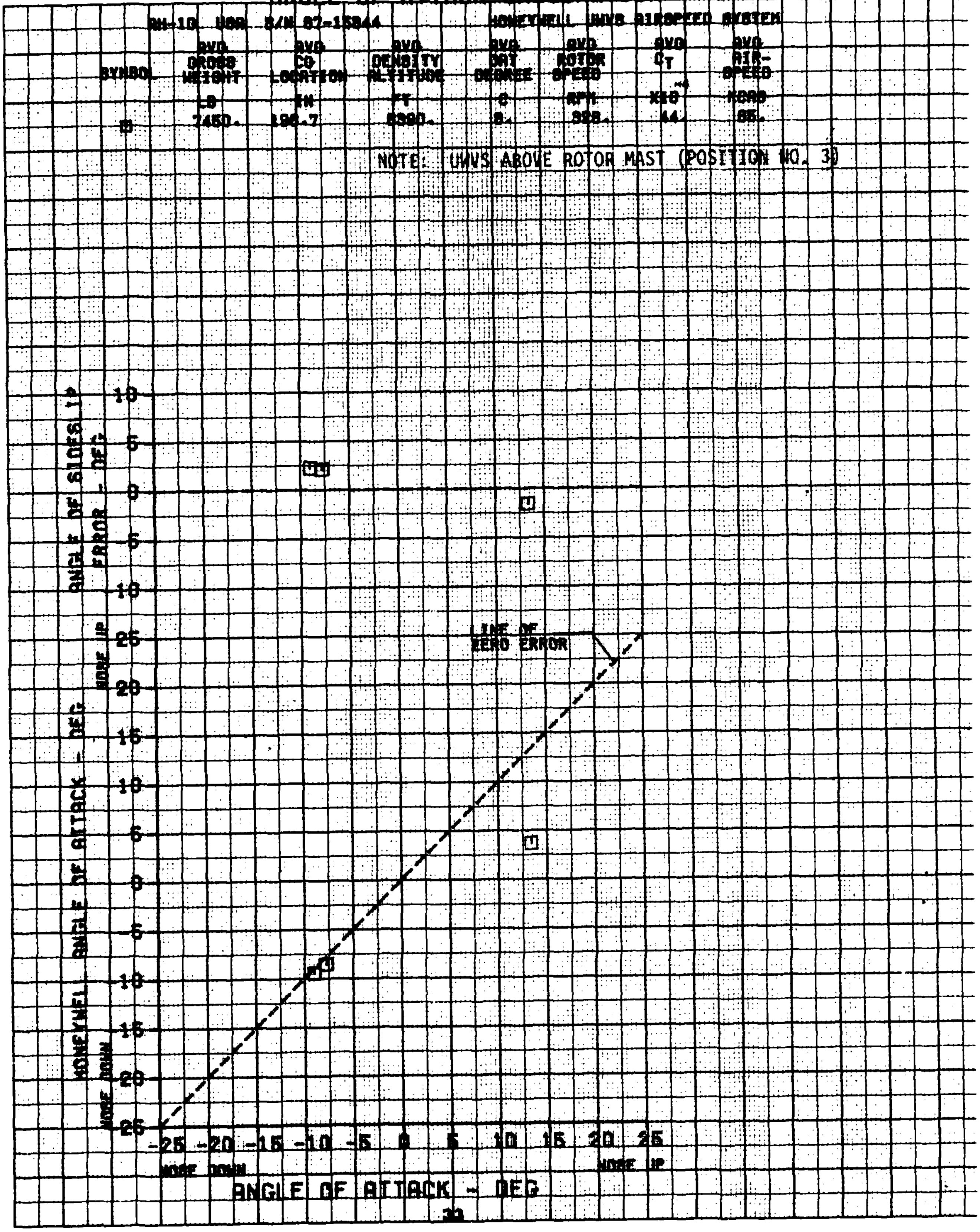


FIGURE 13
ANGLE OF SIDESLIP CALIBRATION

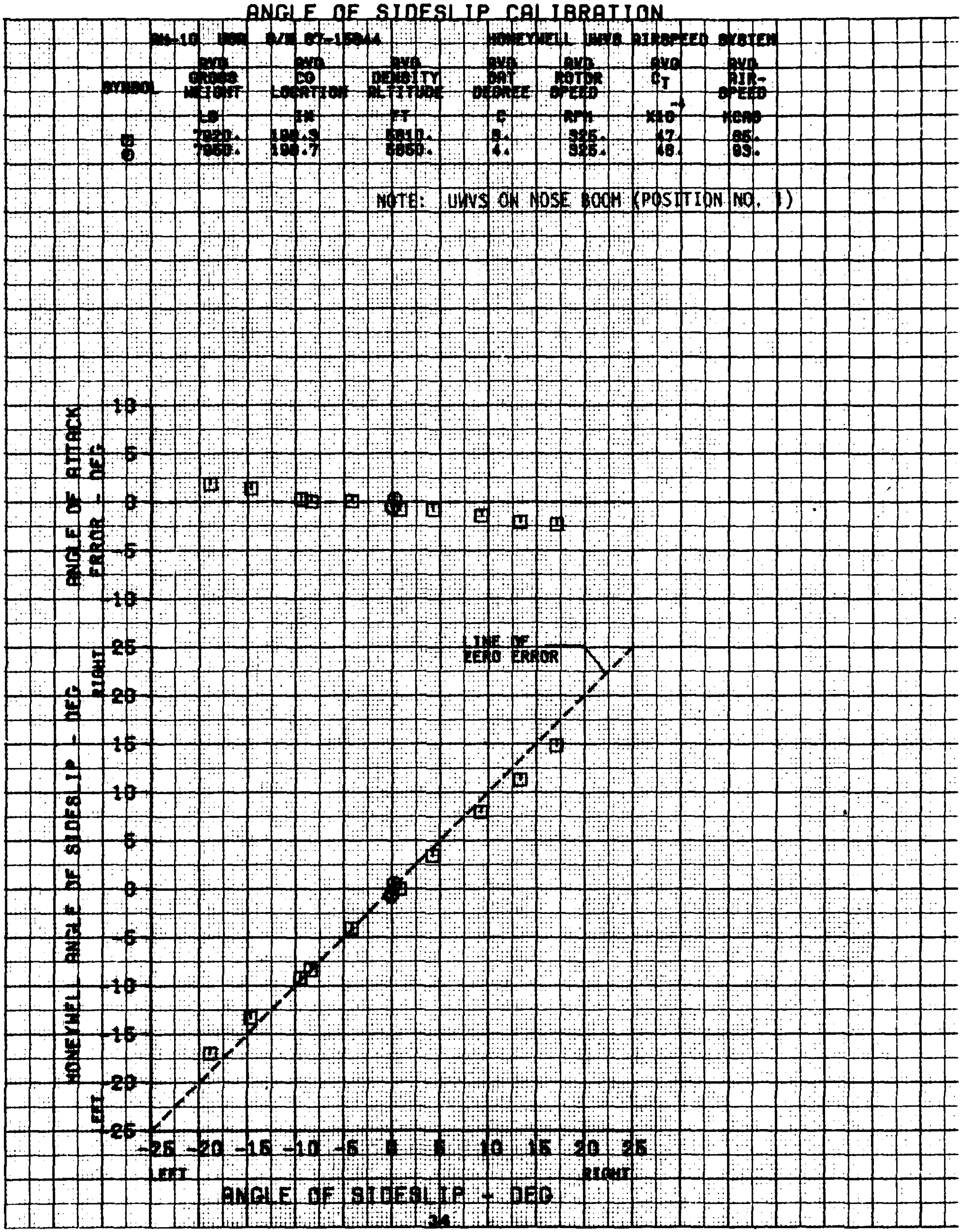


FIGURE 14

ANGLE OF SIDESLIP CALIBRATION

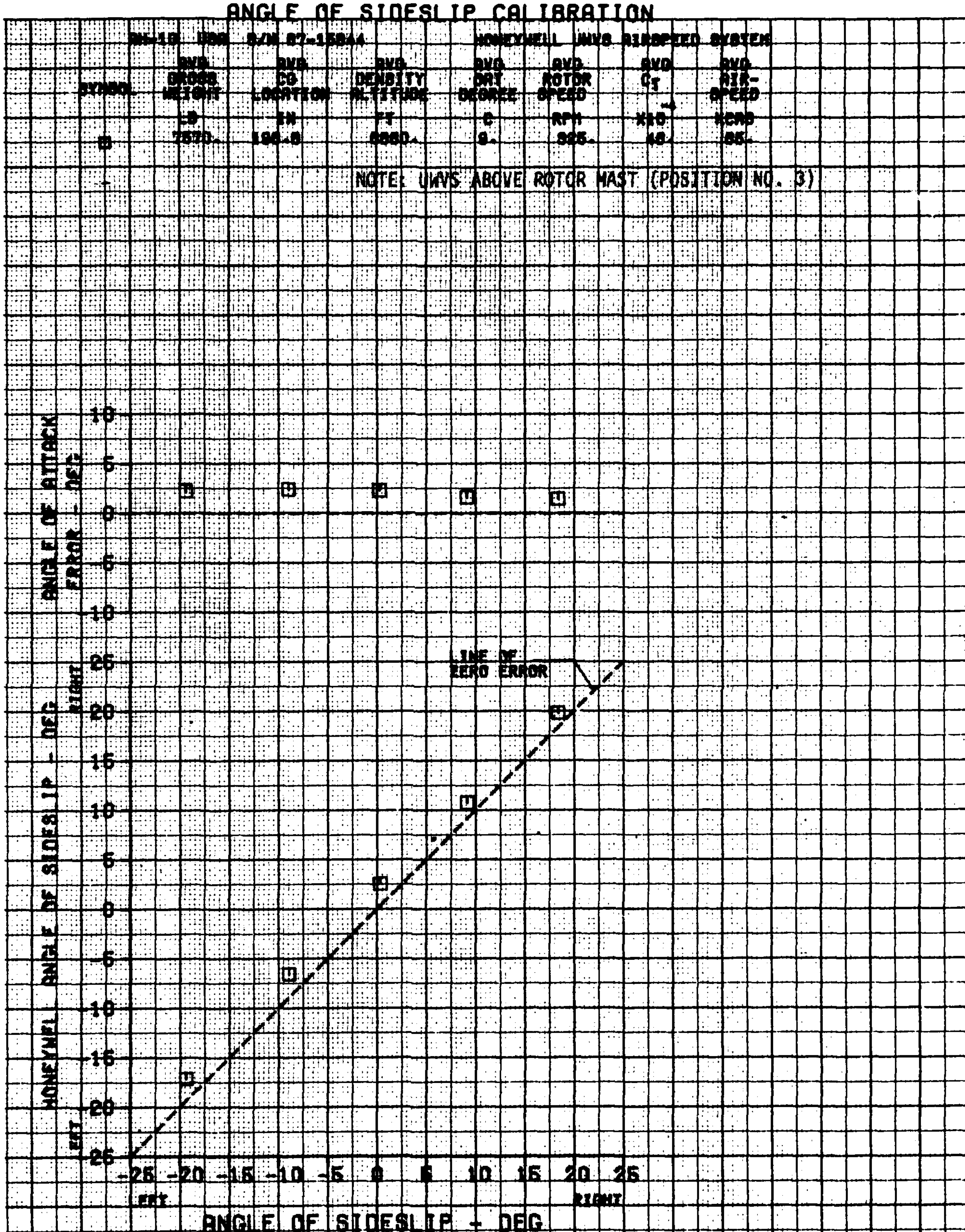


FIGURE 15

AIRSPEED CALIBRATION WITH HONEYWELL SYSTEM MOUNTED ON A GROUND VEHICLE

NOTES:

1. TRUE AIRSPEED OBTAINED FROM AN ANEMOMETER MOUNTED ON THE PACE VEHICLE.

2. THE HONEYWELL SENSOR WAS MOUNTED BACKWARDS TO OBTAIN REARWARD SPEEDS.

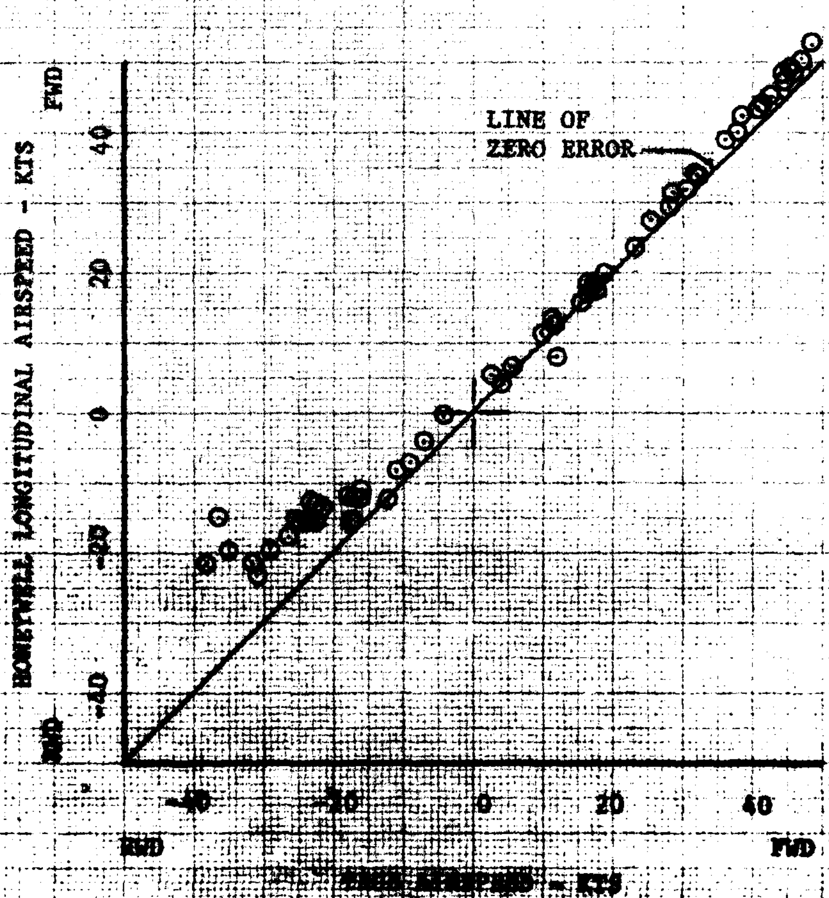


FIGURE 16
AIRSPEED CALIBRATION WITH HONEYWELL SYSTEM MOUNTED ON A GROUND VEHICLE

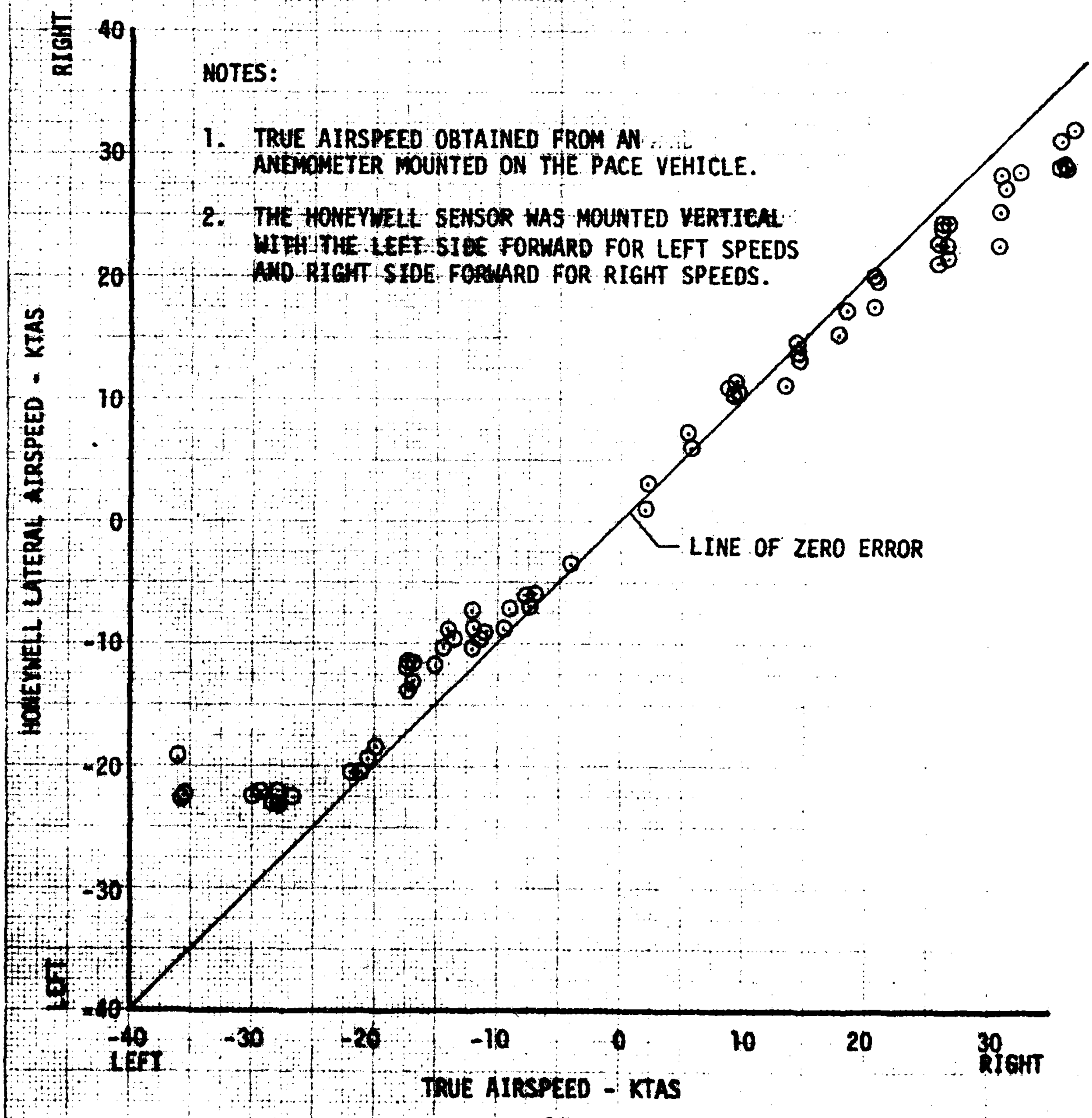
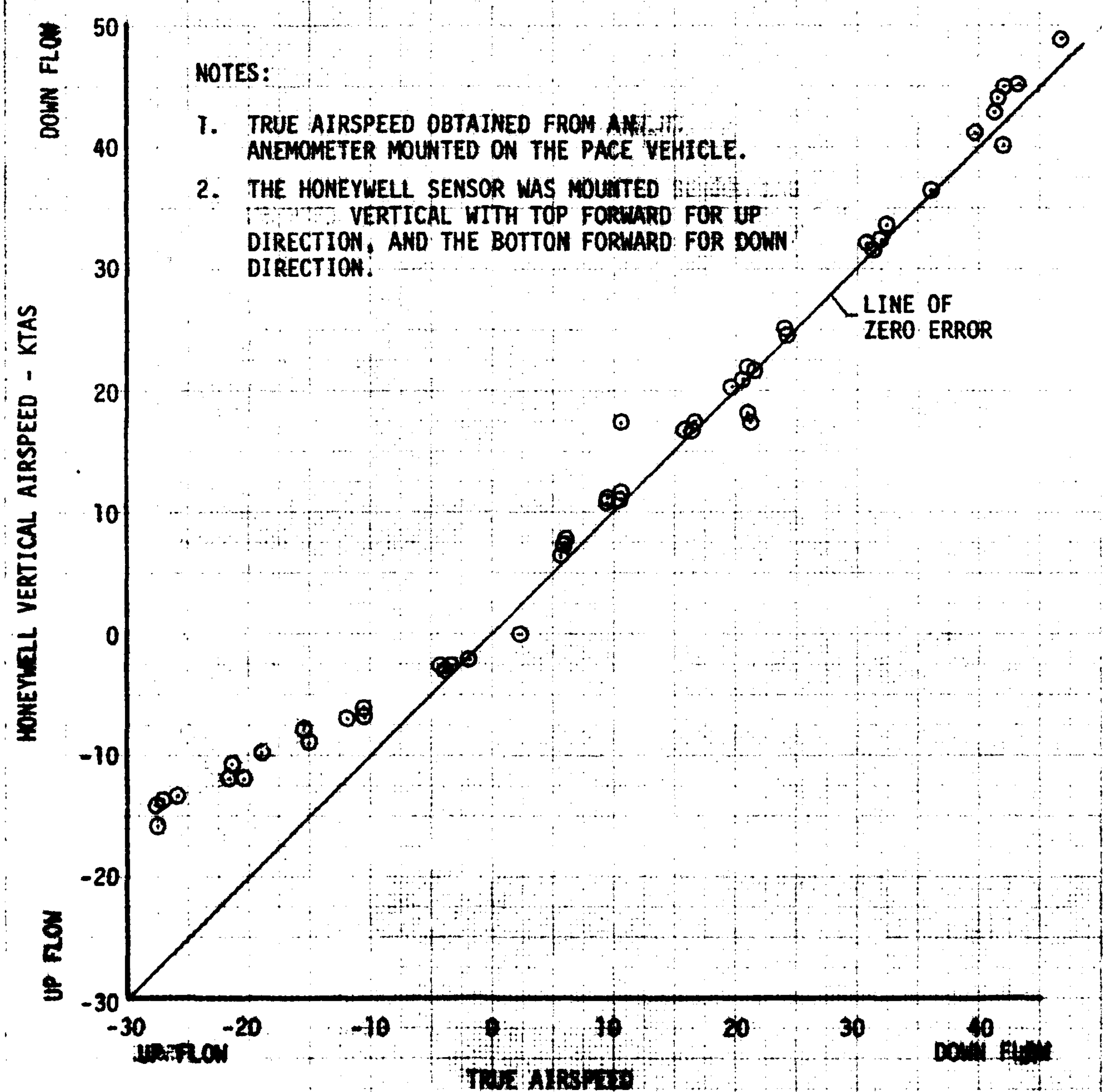


FIGURE 17
AIRSPEED CALIBRATION WITH HONEYWELL
SYSTEM MOUNTED ON A GROUND VEHICLE



APPENDIX E. WIND TUNNEL DATA

1. A calibration of the UWVS system in the Honeywell subsonic wind tunnel was made after the flight tests were completed. The purpose of these tests was to generate complementary data to that secured in the field tests. The wind tunnel was used to simulate and test some of the same wind flow conditions as specified in the flight tests, without the influence of the rotor downwash turbulence. The flight test conditions measured in the wind tunnel concerned forward and backward longitudinal airflow, upward and downward vertical airflow, and left and right lateral airflow. Parameters of the UWVS examined included UWVS system velocity gain and linearities for the opposite directions of airflow, temperature probe airflow problems, velocity limits to system linearity, and discovery of any other system anomalies. The wind tunnel test results are shown in figures 1 through 5.

2. Initial wind tunnel measurements showed that turbulent airflow across the probe structure caused missing time pulses to occur within the probe's time measurement system. Missing time pulses caused over-scale voltages to aperiodically saturate the normal system signal processing electronics, giving erratic air data outputs. The design of the probe electronics anticipated the existence of missing pulses and was designed to reject bad data such as radical changes in transmission times or missing pulses. During early wind tunnel testing, a fault in the noise rejection circuitry was located and repaired before the wind tunnel data were taken.

3. The results of the wind tunnel data on the longitudinal calibration are shown in figures 1, 2, and 3. Forward and rearward longitudinal airflow data curves for multiple wind tunnel runs are linear, repeatable, and have the same (gain) slopes. Forward data to +198 knots and rearward data to -48.6 knots show the linear range of the probe in the longitudinal direction. No data scattering was evident in the wind tunnel data for airflow in either the forward (+WX) or rearward (-WX) directions. However, pace car data in the rearward direction showed data scattering starting at about -20 knots and becoming severe at -35 knots (fig. 15, app D). The wind tunnel data did not show any random variation for rearward airflow of up to -48.6 knots, which was due to the correction of the missing time pulse problem.

4. Vertical airflow calibrations (+WZ) (fig. 4) show linear airflows for (+WZ) downflow to 58.3 knots. The upward vertical airflows (-WZ) show a different measured velocity gain than the (+WZ) airflows. The measured differences between the (+WZ) and (-WZ) velocity gains are due to the shadowing of transmitter #1 to receiver #1 (TX1-RX1) signal path from the true (-WZ) wind velocity by the receiver support arm. The (-WZ) gain slopes are consistent between the instrumented pace car readings and the wind tunnel data. The measured wind tunnel vertical airflow data were repeatable and showed no random variation when measured at vertical airflows to (WZ) = 58.3 knots. The corresponding pace car data were stable only to upward airflows less than (WX) = -15 knots. The stability improvement of the wind tunnel vertical airspeed data over that of the pace car

FIGURE 1
HONEYWELL UWVS AIRSPEED SYSTEM
LONGITUDINAL AIRSPEED CALIBRATION IN
THE HONEYWELL WIND TUNNEL

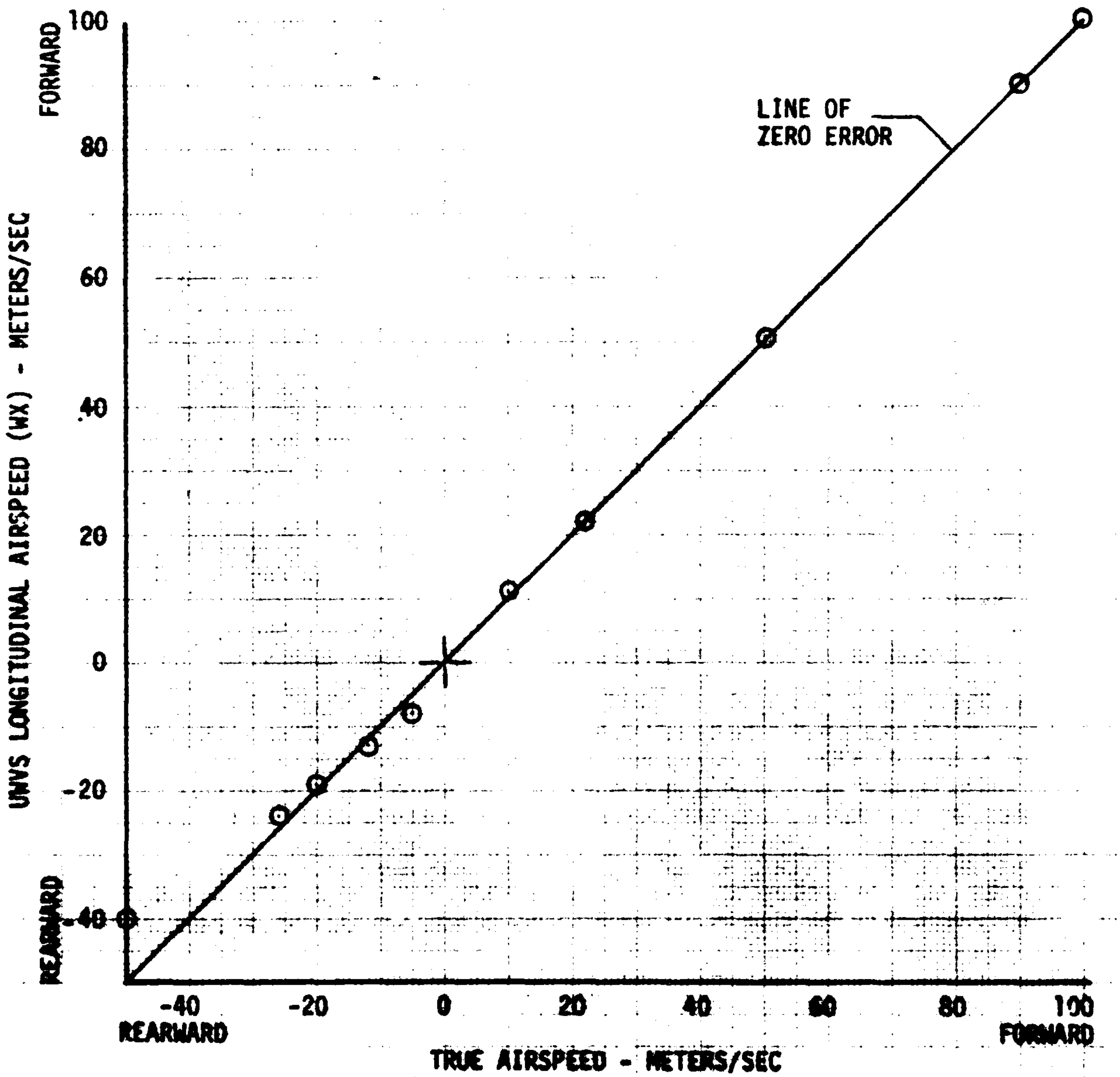


FIGURE 2
HONEYWELL UWVS AIRSPEED SYSTEM
LONGITUDINAL AIRSPEED CALIBRATION IN
THE HONEYWELL WIND TUNNEL

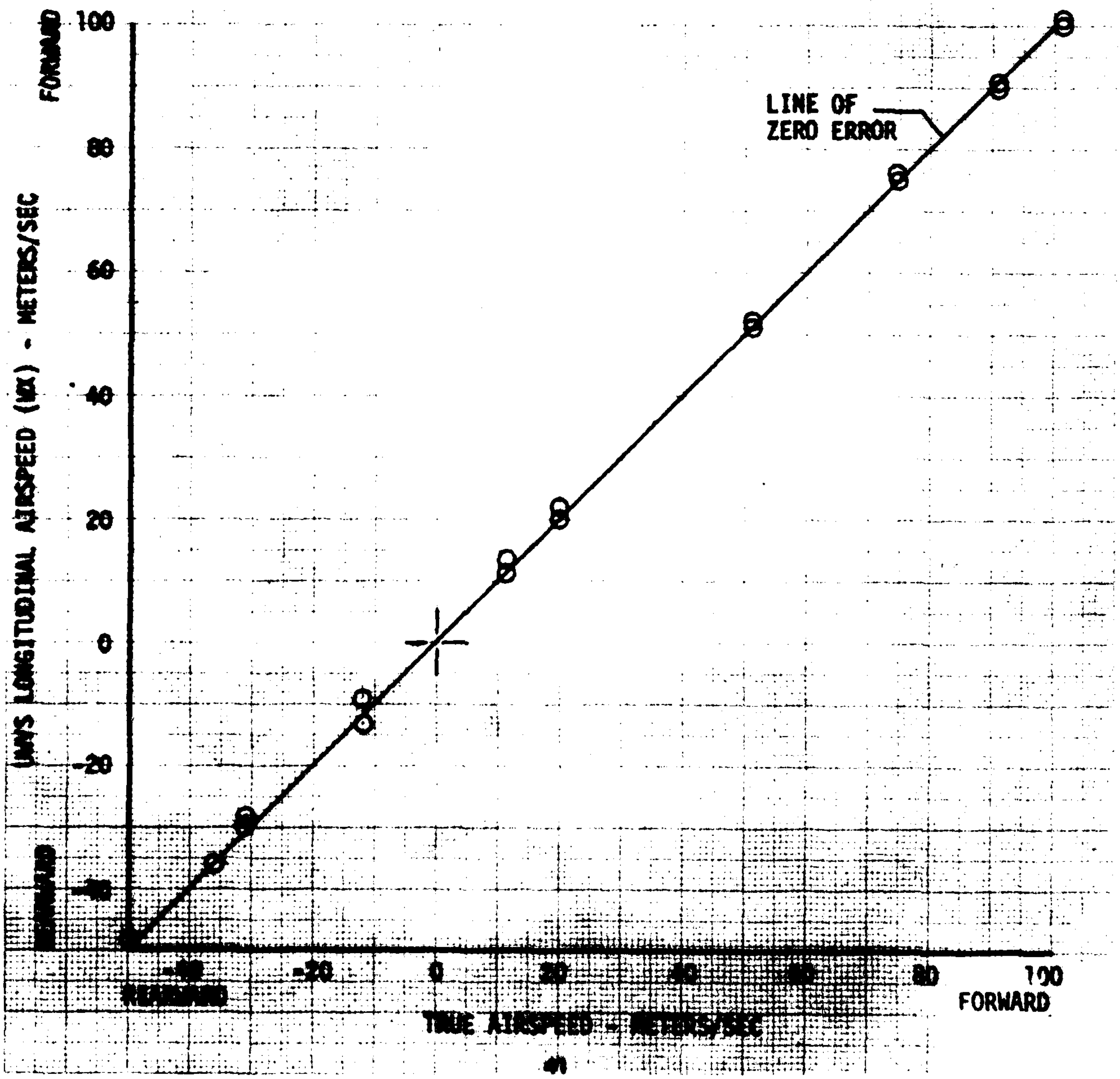


FIGURE 3
HONEYWELL UWVS AIRSPEED SYSTEM
LONGITUDINAL AIRSPEED CALIBRATION IN
THE HONEYWELL WIND TUNNEL

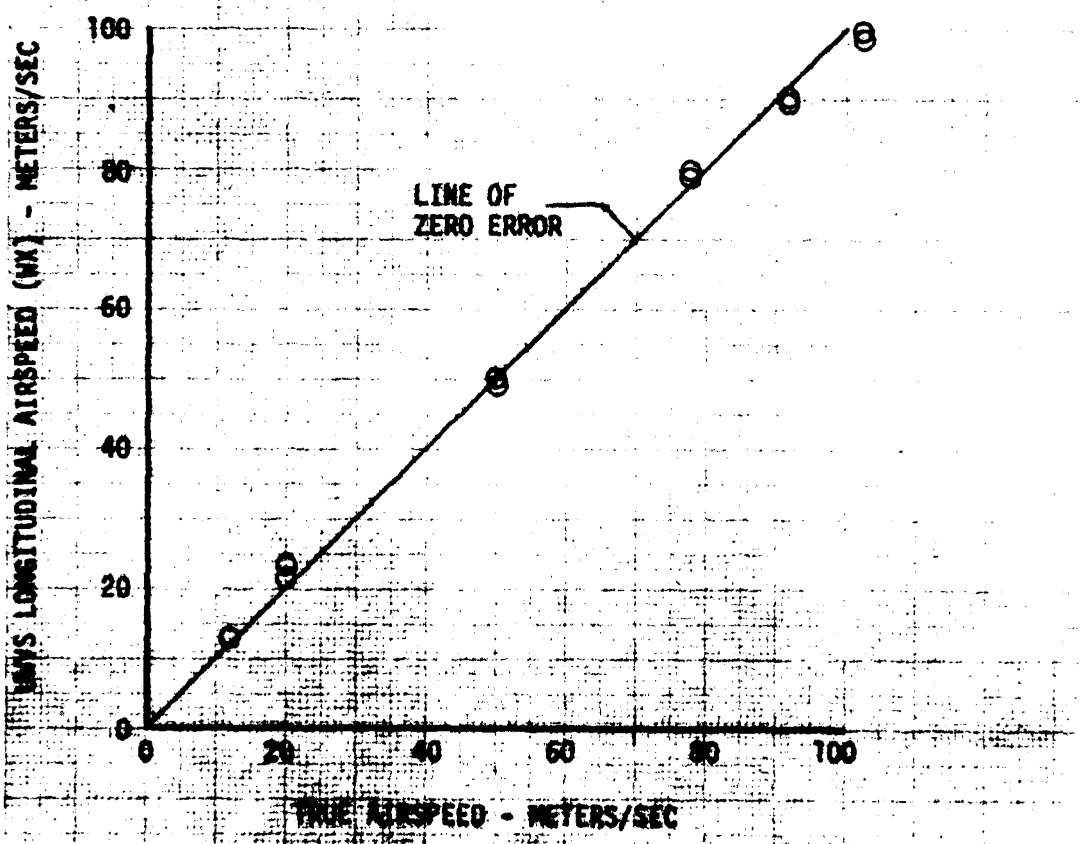


FIGURE 4
HONEYWELL UVWS AIRSPEED SYSTEM
VERTICAL AIRSPEED CALIBRATION IN
THE HONEYWELL WIND TUNNEL

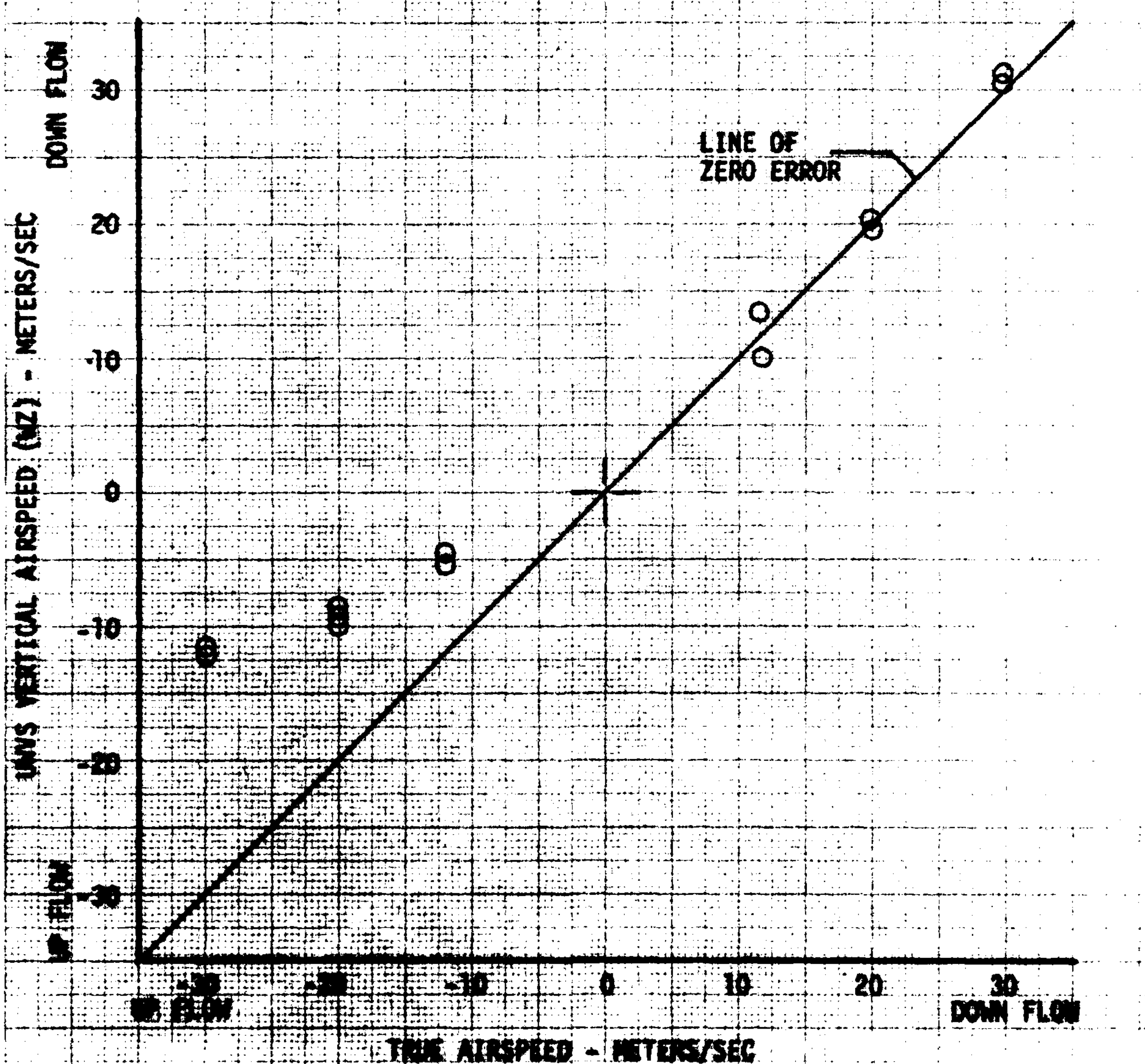
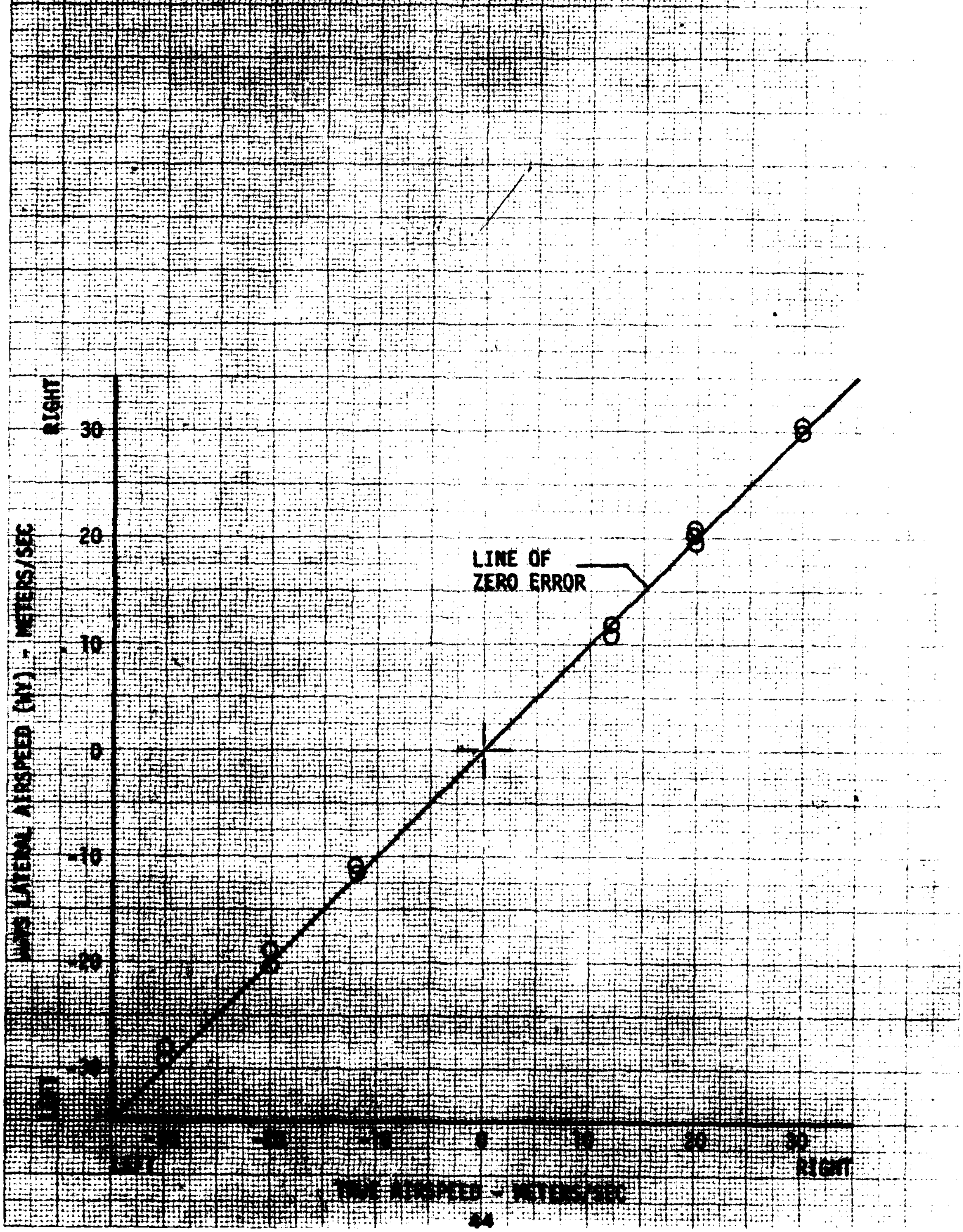


FIGURE 5
HONEYWELL UMWS AIRSPEED SYSTEM
LATERAL AIRSPEED CALIBRATION
IN THE HONEYWELL WIND TUNNEL



is due to the correction of faulty noise rejection circuitry within the probe electronics before the wind tunnel data were run.

5. The lateral airflow calibration (+WY) data were taken for the range of +58.3 knots for the probe mounted in the wind tunnel (fig. 5). The (WY) measured data are linear, repeatable, and accurate over the stated range. No discontinuous wind tunnel behavior was noted, as was present in the pace car testing due to the faulty noise processing circuitry.

6. Airflow through the temperature probe was satisfactory in the moving air of the wind tunnel.

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